ELECTRICAL ENGINEERING

WITH PARTICULAR REFERENCE TO

CONDITIONS IN BENGAL.

Six Lectures delivered in March 1900 at the Civil Engineering College, Sibpur,

BY

J. W. MEARES,

FELLOW OF THE ROYAL ASTRONOMICAL SOCIETY,
MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS,
ELECTRICAL ENGINEER TO THE GOVERNMENT OF BENGAL.

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APPENDIX I.

Table of copper conductors for electrical work.

S. W. G.	Area, square inches.	Resistance in ohms per 1,000 feet at 60° F.	Weight in lbs. per mile.	Rules of the Institution of Electrical Engineers, England.			
				Maximum current for high external temperatures.	Total length in lead and return giving 1 volt drop. Yards.	Minimum thickness of dielectric in thousandths of an inch.	Minimum insulation resistance in megohms per mile or rubber cables.
1	2	3	4	5	6	7	8
18,62 38,97,40	·0018	1·45	[illegible]	3·1	23	35	1,200
3/22	·0019	1·21	38·5	3·3	23	36	1,200
17 130 40	·0024	[illegible]	[illegible]	4·0	25	36	1,200
3/20	·0031	2·61	[illegible]	4·8	26	38	1,200
16,110 38,172 40	·0032	[illegible]	[illegible]	4·9	27	36	1,200
15	·0040	1·98	[illegible]	5·9	28	37	800
7/22	·0044	[illegible]	[illegible]	6·2	28	38	800
14,172 38,7/21½	[illegible]	1·60	[illegible]	[illegible]	29	38	850
3/18	·0055	1·50	112	7·5	30	40	600
7/20	·0072	[illegible]	[illegible]	[illegible]	31	41	600
7/18	[illegible]	[illegible]	[illegible]	[illegible]	37	44	600
19/20	[illegible]	[illegible]	[illegible]	[illegible]	39	48	600
7/16	[illegible]	·352	[illegible]	[illegible]	40	49	600
19/18	[illegible]	[illegible]	[illegible]	31·	45	54	600
7/14	[illegible]	[illegible]	[illegible]	52	15	54	400
19/16	[illegible]	[illegible]	[illegible]	[illegible]	51	62	400
19/14	[illegible]	[illegible]	[illegible]	70	56	70	400
37/16	[illegible]	[illegible]	[illegible]	83	59	75	400
19/12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	82	300
37/14	·1960	[illegible]	[illegible]	[illegible]	64	86	300
61/15	[illegible]	[illegible]	[illegible]	150	67	[illegible]	300
61/14	[illegible]	[illegible]	[illegible]	170·	71	102	300
37/12	[illegible]	[illegible]	[illegible]	[illegible]	73	103	300
61/12	[illegible]	[illegible]	[illegible]	[illegible]	82	[illegible]	300
91/12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	114	300
91/11	[illegible]	[illegible]	[illegible]	120·	94	[illegible]	300

Details of solid conductors.

S. W. G.	Diameter, inches.	Area, square inches.	Resistance in ohms per 1,000 feet at 60° F.	Weight in lbs. per mile.
1	2	3	4	5
0000000	·500	·1963	·041	3,995
000000	·464	·1691	·048	3,440
00000	·432	·1466	·056	2,980
0000	·400	·1257	·065	2,560
000	·372	·1087	·075	2,210
00	·348	·0951	·086	1,930
0	·324	·0825	·099	1,680
1	·300	·0707	·115	1,410
2	·276	·0598	·136	1,220
3	·252	·0499	·163	1,016
4	·232	·0423	·193	859
5	·212	·0353	·231	712
6	·192	·0289	·282	588
7	·176	·0243	·335	495
8	·160	·0201	·405	408
9	·144	·0163	·500	331
10	·128	·0128	·634	260
11	·116	·0105	·772	215
12	·104	·0085	·950	172

Note.—No wire of less than [illegible] inch diameter may be used in any street for electric lighting purposes.

APPENDIX II.

Table giving the sizes of various wires which will be fused by a given current.*

(SIR WILLIAM PREECE.)

Current in ampères.	Tin wire— Diameter, inches.	Tin wire— Approx. S. W. G.	Copper wire— Diameter, inches.	Copper wire— Approx. S. W. G.
1	2	3	4	5
1	·0072	36	·0021	47
2	·0113	31	·0034	43
3	·0149	28	·0044	41
4	·0181	26	·0053	39
5	·0210	25	·0062	38
10	·0334	21	·0098	33
15	·0437	19	·0129	30
20	·0529	17	·0156	28
25	·0614	16	·0181	26
30	·0694	15	·0205	25
35	·0769	14½	·0227	24
40	·0840	13½	·0248	23
45	·0909	13	·0268	22
50	·0975	12½	·0288	22
60	·1101	11	·0325	21
70	·1220	10	·0360	20
80	·1334	9½	·0394	19
90	·1443	9	·0426	18½
100	·1548	8½	·0457	18
120	·1748	7	·0516	17½
140	·1937	6	·0572	17
160	·2118	5	·0625	16
180	·2291	4	·0676	16
200	·2457	3½	·0725	15
250	·2851	1½	·0841	13½

* From "The 'Electrician' Electrical Trades Directory, 18[illegible]."

APPENDIX III.

RULES FOR ELECTRIC LIGHT AND POWER INSTALLATIONS.

RECOMMENDED FOR ACCEPTANCE BY MEMBERS OF THE CALCUTTA FIRE ASSURANCE AGENTS' ASSOCIATION.

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I.—CONDUCTORS.

Conductivity and size.

(*a*) All conductors are to be of tinned copper, of at least 98 per cent. conductivity. Their sectional area must be such as to allow in no case more than 1,000 ampères per square inch for low tension currents, or 750 ampères per square inch for high tension currents.

In reckoning the current to be carried by any conductor, every current-consuming apparatus on that circuit must be calculated as being at its maximum load, and no lamp may be taken as being of less than 16 candle-power.

Temperature limit.

(*b*) Conductors shall, apart from the above considerations, be of such size that when the maximum current is passing continuously through them their temperature shall not exceed 130° Fahr. Owing to the high temperatures to which conductors are subjected by the Indian climate, it will probably be necessary in some cases to use a lower current density than that stated above, as the electric heating should be practically nil.

Gauge of wires.

(*c*) No unstranded conductor smaller than No. 18 S.W.G. nor larger than No. 16 S.W.G. may be used, except that in fittings with branches for not more than one lamp single wires of not less than No. 20 S. W. G. may be used.

Drop of pressure in conductors.

(*d*) In addition to the above precautions, the fall of pressure in private houses between the main switch-board and the furthest lamp must not exceed 2 per cent. under full load.

II.—INSULATION.

General.

(*a*) All conductors used inside buildings must be insulated, and the insulated cable must be covered in, except where these rules specifically state to the contrary or the permission of the Association has been obtained to do otherwise.

Nature of insulation.

(*b*) All materials used for insulating electric lines or apparatus must be of the best quality and thoroughly durable and efficient, having regard to the conditions of its use. Suitable provision must be made for the protection of the insulating material from injury by damp, vermin, or other causes.

Lead covered cable.

(*c*) Where such cable is used that the maintenance of its insulation depends upon an outer covering of lead or other material, great care must be taken to protect exposed ends of conductors from the access of damp at the points where they enter the terminals of any apparatus.

Quality.

(*d*) The insulation resistance of conductors must be in no case less than 750 megohms per mile for use in dry places and 1,000 megohms per mile for damp places.

III.—JOINTS.

General.

(*a*) Joints should be avoided as far as possible. Where necessary, they must be mechanically and electrically perfect, and in all cases soldered with rosin as a flux.

The protective covering over the rubber must be removed for at least 2 inches on each side of the joint and the rubber tapered down so as to ensure a good union. They must be carefully insulated with at least 6 laps of pure rubber and then water-proof tape.

Vulcanised joints.

(*b*) In damp places or in every place where the pressure is over 200 volts it is recommended that the joints be vulcanised, though this is not compulsory.

IV.—Concentric Conductors.

These should conform to the rules laid down for single conductors; the insulation resistance of the inner dielectric must be at least 750 megohms per mile.

V.—Flexible Twin Conductors.

Twin flexible must not be used except for pendants and portable fittings.

Where it is necessary to use flexible in a place where it is liable to damp or abrasion it must be of the best quality of that class where the two conductors are covered over to make a single circular cord.

For use on 220 volt circuits it is imperative that the highest quality only be used, and the radial thickness of the dielectric must not be less than 20 mils

VI.—General Arrangements of Installations.

Main switch-board.

(*a*) A single pole switch and a single pole cut-out must be placed on each pole at the point of connection of an installation with the source of supply. These must be mounted on an incombustible base, the connections being as simple as possible. Exposed conducting metal parts of different polarity on switch-boards must be separated by an incombustible partition, or preferably mounted on different bases kept well apart. The switches may be linked together by means of a bar of insulating material.

Distributing.

(*b*) From the main switch-board the best and safest plan of wiring is to run one or more circuits, each controlled on both poles by cut-outs and switches, to convenient distributing centres, these conductors being kept entirely free from joints and tapping. From these points single lamp circuits should be run as required, but small circuits carrying not more than 550 watts may be taken off with as few joints as possible in them. Joints *en route* should be specially avoided where the circuit supplies a fitting containing several lights. Every such branch circuit must be controlled by a cut-out on each pole and a switch at the distributing point, and the 2 poles must be kept on separate bases at least 5 inches apart. All circuits should be distinguished by a letter or number at the distributing board to enable them to be easily traced on the wiring plan.

Tree system of wiring.

(*c*) This system is not recommended for wiring dwelling houses.

Where adopted, fuses must be introduced on each pole at such intervals that each protects the smallest branch between it and the next fuse or up to the end of the circuit as the case may be.

Three-wire system.

(*d*) Switches must not be placed on the third wire unless they are linked with those on the outers.

VII.—Erecting Conductors.

Accessibility.

(*a*) All conductors should, as far as possible, be arranged so that they can be inspected easily.

Manner of placing.

(*b*) Except where laid down to the contrary in these rules, conductors must be either enclosed in wood casing or approved incombustible tubes.

VIII.—Wood-casing system.

General rules.

(*a*) Wood casing must be of dry well seasoned teak and coated both inside and out with a moisture-proof varnish before erection. It must have a continuous central fillet of not less than ½ inch width in any case and 1 inch for mains. The capping must be screwed

down at the sides, brass screws being used in places extra liable to damp. Joints in the casing should be carefully made and puttied; where the casing turns a sharp angle, special care must be taken that the insulation is not cut by sharp angles or projections in the wood.

Bunching.

(b) Bunching of wires of different potential in the same groove of wood casing is prohibited, and where the pressure is over 200 volts no bunching will be allowed, without special permission, except in approved metal tubes.

Passing through walls.

(c) Where conductors pass through walls they must be run in porcelain or other approved tubes, which should be filled in afterwards with dry sand or other suitable incombustible substance.

IX.—Tube System.

Tube system.

(a) If tubes are used, they must be of iron or other approved metal, and may advantageously be lined [illegible] with a non-conducting substance. [illegible] must be drawn into one tube, which must be of such size that the insulation of the conductors will not be damaged [illegible], and that they can be easily withdrawn. [illegible] wiring, and no joints are allowed in the tubes, [illegible] inspection being used for these purposes.

If the system is alternating current both conductors must be placed in one tube.

Lead-covered cable.

(b) Lead-covered cables buried in walls are not recommended.

X.—Unencased Conductors.

Subject to the permission of the Association in every case, wood casing may be dispensed with, provided that the conductors are [illegible] at least 12 feet from the floor, clear of all heating and shafting, and inaccessible without a ladder. In all such cases the conductors must be either run on porcelain insulators or else supported on and held down by cleats, approved by the Association, at such distances apart as to prevent sagging. The conductors must be kept apart from one another, and any other conducting substance by at least 6 inches for main and 2 inches for branch circuits, or double these distances where the pressure is higher than 200 volts, unless special permission to the contrary has been given. Wood casing must, however, be invariably used in such portions of hazardous risks as are used for the storage of fibres, or where flour or dust may be present in the air in quantity.

XI.—Party Walls.

Where conductors have to pass through party or division walls between two risks, permission must be first given by the Association, and the conductors must be so run that a fire cannot be communicated by means of them.

XII.—Earthing.

No earthing or connection of conductors to gas or water pipes is allowed without permission of the Association.

XIII.—Fittings.

All switches, cut-outs, ceiling-roses and connectors are to have their bases and covers of incombustible material, well insulated as to the base, and they should be placed only in dry places as far as possible. The space between the terminals must be sufficient to prevent any permanent arc, and the covers and fixing screws must be kept clear of the parts carrying current.

XIV.—Switches.

Switches must be constructed—

(*a*) With ample rubbing contact to prevent overheating.

(*b*) With a quick break of sufficient length to prevent the possibility of an arc forming, having regard to the pressure of the supply.

(*c*) So that they cannot remain in an intermediate position between on and off.

(*d*) In the case of circuits with a pressure over 200 volts the cover and handle as well as the base should be of non-conducting material.

XV.—Cut-outs.

Where required.

(*a*) Wherever the sectional area of any conductor is reduced, it must be protected by a single pole cut-out on each pole.

Double pole cut-outs.

(*b*) Double pole cut-outs are only permitted when the two poles are in separate compartments with an incombustible partition. They are not recommended.

Fuses.

(*c*) Fuses must be carefully calculated to melt at 50 per cent. above their normal current: standard fuses are strongly recommended, and unless these are used consumers should on no account attempt to replace their own fuses.

Fuses in ceiling roses.

(*d*) Fuses should not be placed in ceiling roses. By carefully following out the rules with regard to circuits they are rendered unnecessary. Where the pressure is over 200 volts they are forbidden, and the terminals (if any) must be bridged by a piece of thick copper wire.

XVI.—Lamp-holders.

Ordinary.

(*a*) Lamp-holders must be of an approved type; where the pressure is over 200 volts they must have a partition of porcelain or other approved material between the terminal.

Switch lamp-holders.

(*b*) These are not allowed when the pressure is over 200 volts, unless of special make for the pressure.

XVII.—Connectors

Floor sockets.

(*a*) Floor sockets are not allowed without the permission of the Association.

Wall sockets.

(*b*) Wall sockets must be entirely constructed of an incombustible material and carefully fixed.

On circuits where the pressure is over 200 volts special care must be taken that the clearance is sufficient to prevent an arc being started if the circuit is broken at a connector.

Concentric sockets.

(*c*) When a concentric type is used it must be such that it cannot easily be short-circuited by a piece of metal, and the insulation between poles should be such and so placed that it will not readily break or chip.

Fuses in connectors.

(*d*) When circuits leading to wall connectors for portable lights are fused on both poles at the distributing point, and carry not more than 500 watts, fuses at the connectors are not necessary. When the circuit is for purposes other than light a fuse must be placed at the connector.

XVIII.—Fixtures.

Electroliers and brackets.

(*a*) Electroliers and brackets should be effectually fixed to the ceiling or wall and insulated from it by a varnished wooden block. They must not in any way depend upon the conductors for their

support. Great care must be taken in wiring them that the insulation is not damaged and that no sharp projecting metal parts have been left in the manufacture.

Imitation candles.

(b) If imitation candles are used they must be made of non inflammable material.

Gas fittings.

(c) If gas fittings are converted for use for electric light they must be insulated from the gas pipe, and permission to convert must be obtained beforehand from the Association.

Combined electric light and gas fittings.

(d) These are not in any case permitted.

XIX.—Conductors entering Fittings.

Conductors where they enter the terminals of any fittings must have the braiding removed down to the vulcanized rubber, which should nearly come up to the terminal. Care must be taken that no loose ends are left about, and that the wires are fitted in such a way as to prevent the occurrence of short-circuits, loose contacts, or leakage. It is recommended that the wires composing a flexible be soldered together where they enter a terminal. No conductor may touch the wall when entering a fitting.

XX.—Lamps.

Incandescent lamps.

(a) Incandescent lamps must be kept at a safe distance from combustible materials, especially fabrics in shop windows and manufactories. If silk, paper, or similar shades are used they must be kept well clear of the lamp. Lamps should be renewed when appreciably blackened.

High candle-power lamps.

(b) High candle power lamps must be kept at least 3 feet from all inflammable materials. They are forbidden in risks where fluff, dust or explosive gas is liable to accumulate.

Arc lamps.

(c) Arc lamps must be guarded by lanterns or netted globes, to prevent damage from incandescent pieces of carbon or sparks. They and their resistances must be insulated at their supports and kept away from wood, &c., by at least 6 inches horizontally and 2 feet vertically. They must have cut-outs on both poles when supplied from constant potential mains.

XXI.—Electro-motive force.

No circuit in a house may be at a higher pressure than 250 volts if direct current, or 125 volts if alternating current. Terminals in a house bearing a higher pressure than this must be placed at a distance of not less than 6 feet from one another.

XXII.—Lightning.

Any installation taking its supply from overhead mains must be adequately protected by a lightning-arrester of approved form.

XXIII.—Testing.

Method of testing insulation resistance.

(a) A testing pressure of not less than 100 volts, or, in case of an installation where the E.M.F. is higher than 200 volts, of 200 volts, must be employed. All lamps and appliances to be used must be connected up to the conductors, and all fuses in place during the test to "earth." A test "between poles" is to be taken also.

Continuous current.

(b) If the supply is "continuous current" the insulation resistance in either test must not be less than the quotient of 10 megohms divided by the maximum number of ampères required.

Alternating current.

(c) If the supply is "alternating current" the insulation resistance should be double the above figures.

XXIV.—Small Motors for Domestic use.

Ordinary.

(a) An entirely separate circuit, protected by a cut-out and a switch on each pole, should be run for every motor, from the distributing centre.

Motors must have an approved fireproof material separating them from any woodwork on which they may rest, and they may not be placed in any position which is considered hazardous by the Association.

Suspended motors.

(b) Suspended motors must be hung from an insulated support in such a way that no strain is put on the conductors. All methods of using these must be approved by the Association. The flexible cords supplying current to motors of these classes must be run in such a way that persons cannot accidentally catch against them.

XXV.—Electric Heating or Cooking.

Every piece of apparatus must have a cut-out and a switch on each pole. It must be placed upon fire-proof material, and the leading-in wires must be such that their insulation will stand the conditions of use and temperature to which they are subjected without deterioration.

XXVI.—Resistances.

Resistances must be mounted on incombustible bases, and have well ventilated metal covers. They must be placed away from all inflammable material, and their construction and mounting be such that leakage cannot take place through their instrumentality.

XXVII.—External Aerial Lines.

All external aerial conductors must be kept at least 7 feet from any stack of fibrous or inflammable material.

XXVIII.—Power Installations.

Housing of [illegible]

(a) Electrical generating apparatus and motors other than those already [illegible] together with their regulating [illegible] must be placed in a room set apart for the purpose, or in the [illegible] room. [illegible] any [illegible] into this room and that a fire [illegible] spread to outside it.

Precautions.

(b) Every dynamo or motor [illegible] switch on each pole, must be [illegible] from earth, and not placed on [illegible] a sheet of incombustible material. [illegible] have [illegible] out-put marked on it, and must be [illegible]

Alternate current transformers.

[illegible] be placed in a special separate [illegible] the permission of the Association [illegible] being submitted.

XXIX.—Batteries.

Primary [illegible] in a well ventilated place. They must [illegible] everything liable to damage [illegible] by [illegible] Only incandescent lamps may be used [illegible]

XXX.—Hazardous Risks.

In the case of [illegible] drapers), jute, cotton, paper, sugar, corn, [illegible] hazardous, owing to the storing or [illegible] substances, high temperature, or dust, the system of [illegible] the Association approve of.

APPENDIX IV.

(From "The Potentiometer," by W. Clark Fisher, pages 2—6.)

"DESCRIBING the potentiometer as briefly as possible, it might be said to consist in its present form of 15 sections of wire connected in series, 14 of which are in the form of coils concealed in the instrument, the 15th being stretched along a scale suitably divided; they are accurately adjusted with each other, so that with a fixed E. M. F. of 1·5 volt over the whole each section has a fall of $\frac{1}{10}$ of a volt, the scale beneath the slide wire having 1,000 divisions, each corresponding therefore to $\frac{1}{10,000}$th of a volt (see Fig. 1).

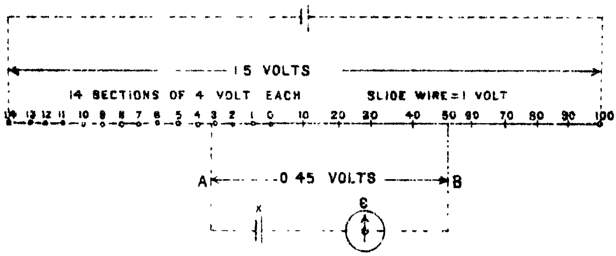


Fig. 1.

"The unknown quantity x to be measured is placed in series with a galvanometer G, and attached to the movable contacts A and B, the intermediate reading between the contacts or main sections of A being obtained by the movement of B along the slide or scale wire, x is so connected up that its E. M. F. opposes that of the main circuit. No deflection of the galvanometer takes place when the point of balance between the opposing E.M.F.'s is obtained; such position, supposing it to exist in the diagram given, would be represented by the contact 4 and 500 divisions of the scale wire, which, taking into account that each main contact is equal to $\frac{1}{10}$th of a volt, and each division to $\frac{1}{10,000}$, the whole is equal to 0·450 of a volt. This represents the ordinary working conditions of the main in strument when used in measuring E.M.F., or current. Under certain

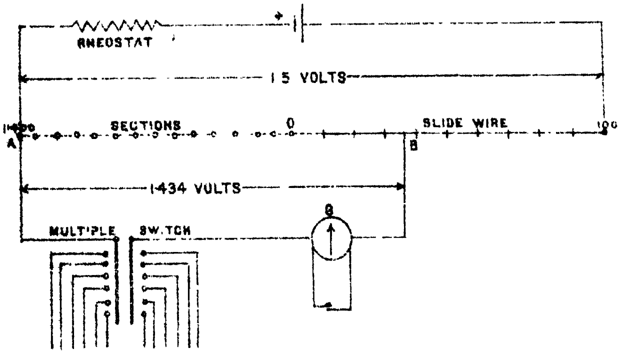


Fig. 2.

circumstances, more especially when measuring resistances, it is advisable to alter the main E.M.F., in which case the values of the sections are correspondingly altered; such conditions will be described as they arise in the study of the capabilities of the instrument.

"Although the above represents roughly the diagram of the main instrument, there are fitted in it certain switches and a rheostat for adding resistance in the main circuit, so reducing the E. M. F. of the secondary cell ordinarily used to the proper value, and for connecting any series of x into circuit in due rotation, so that measurements may rapidly be taken in sequence, there being also a short-circuit key for the galvanometer, and a due array of necessary terminals, the true diagram of the instrument therefore being that shown in Fig. 2.

"In using the instrument for the measurement of power, the first operation necessary is its due calibration, *i.e.*, the adjustment of 1·5 volts at the terminals of the whole of the sections; for, as shown in the diagram, a secondary cell is used as the source of main E.M.F., and having, roughly speaking, an E.M.F. of 2 volts, resistance has to be inserted in circuit to bring it down to the 1·5 volts required. This value is ascertained by substituting for x a known value or standard, *i.e.*, a Clark's standard cell; its temperature is noted, and the two contacts A and B are placed upon the figures corresponding to the value of the cell at that temperature, which we will suppose to be, in the case of Fig. 2, 1·434 (in which it is seen that the contacts A and B are at 14° and 34° respectively), that being the certified value—in Board of Trade volts—of the standard cell at 15° C. Resistance is added in the main circuit until there is no deflection of the galvanometer, due to the fact of the two E.M.F.'s—that in the main and galvanometer circuits—being equal one to the other; the instrument is thus standardised from what afterwards becomes the x circuit, and is then ready for working and obtaining the value of unknown E.M.F.'s. The act of switching *in* the unknown puts the standard cell *out* of circuit, so that no possible accident can happen to it, and it need only be brought into circuit again for occasional check purposes.

"It will be noticed that the maximum observed E.M.F. on the potentiometer is 1·5 volts; all values therefore to be measured must fall within that range. To meet this requirement multiples and sub multiples of the ohm are used, and are so proportioned that their maximum carrying capacity is some definite value proportional to that of the instrument, and it is entirely upon them that the range of the set of apparatus depends. Standards up to the present have been made for the measurement of 10,000 ampères on the one hand, and 3,000 volts upon the other, but this does not in any way suggest the limit, which might almost be described, in the case of current, as illimitable, whilst with voltage the question of insulation alone steps in.

Current Measurement.

"Taking, first, the question of the measurement of current, this is done by passing the current to be measured through a standard low resistance (Fig. 3) of such value that the fall in volts—with maximum current—over the whole does not exceed that measurable on the potentiometer. The usual units adopted by the majority of English central stations allow of standards for maximum currents of 1,500, 750, 150, 15 and 1·5—the last three for meter and lamp testing, the preceding two for machine and instrument tests. To be effectively used with the instrument described they should be so proportioned as to be direct reading, that is to say, the first, with a load of 1 500 ampères, should allow of a fall of 1·5 volts, each section of the instrument being equivalent to $\frac{1}{10}$ of a volt, will therefore correspond to 100 ampères, each division on the scale to 0·1 of an ampère. The second standard should be similarly proportioned, 750 ampères reading at 0·750 volt; the third standard, for 150 ampères, should have 10 ampères for section and 0·01 per division of scale; the fourth, for 15 ampères, having 1 ampère per section and 0·001 per division; the fifth, for 1·5 ampères, having 0·1 per section and 0·0001 per division. If, therefore, any of these standards are placed in the circuit—current through which is to be measured—the fall of E. M. F. over it is balanced on the potentiometer, and value in current read off accordingly direct. For economy in material, or weight when standards are carried about, it is customary in some instances to adopt half values, that is to say, the standard for 1,500 ampères would be half the resistance of that already described, the consequent E.M.F. at full load would be halved, and the value would be read at on 750 the instrument. The fall of volts over standard with full load being ·75, other values would be in similar proportion, and all would need to be multiplied by 2 to obtain two current values. This, however,

whilst giving economy in material, or a standard having twice the carrying

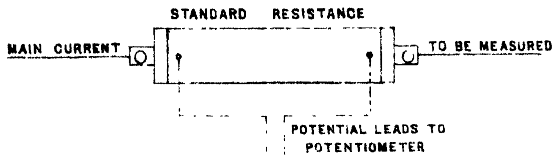


Fig. 3.

capacity of the former, is not to be recommended, as when introduced with other standards having no multiplier, errors arise and quick reading becomes impossible. Recently the question of weight and economy of space, etc., has been overcome by the design of standards of tubular form artificially cooled by the circulation of water and very heavy connections. In this manner a current density of from 25 to 30,000 ampères per square inch is possible, which allows of a very compact standard being constructed. However, this will be treated separately, when the construction of such standards is considered. It is, however, interesting to note in connection with these standards that no danger is to be anticipated in connecting them to the ordinary water-supply, as a moderate length of ordinary hose-pipe amounts to practical insulation. In fact, 30 feet of ordinary three-ply rubber tubing, $\frac{3}{4}$ in. bore, supplied by the Silvertown Company, filled with ordinary "commercial London water" and practically armoured by being laid its whole length along a lead floor, had, when tested from end to end of the liquid with 100 volts, a resistance of one megohm.

"To one not accustomed to the use of the different standards, it is puzzling at times to give, off-hand, the value obtained. Very little practice, however, is required, and a very simple guide to the memory is merely to note the value and maximum carrying capacity. For instance—

$\frac{1}{1,000}$ ohm,	1,500 ampères	at 1·5 volts	or full range of instrument.
$\frac{1}{100}$,,	150 ,,	,, ,, ,,	
$\frac{1}{10}$,,	15 ,,	,, ,, ,,	

Measurement of E.M.F.

"The maximum of E.M.F. ordinarily measureable on the potentiometer, as has been previously described, is 1·5 volts, but for secondary cell tests, etc., it

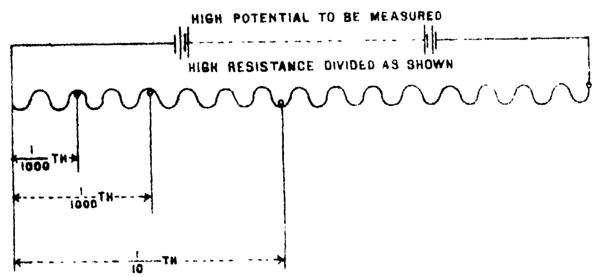


Fig. 4.

may be made 3 volts by adding another secondary in the main circuit, and balancing with the Clark cell at half value, but in that and other cases in which it may be done it is necessary to multiply the reading by 2 to obtain the true result. When, however, some very much higher E.M.F has to be measured, it is necessary to place it across a very high resistance, the fall over some portion of which only is measured (see Fig. 4). For instance, taking a box

of 100,000 ohms, across which is placed 1,000 volts, the fall over 100 ohms corresponding to $\frac{1}{1,000}$ of the total, and represented by 1 volt only, is carried to the potentiometer; in the same manner if it were 100 volts, the fall over 1,000 ohms—or $\frac{1}{100}$ of the whole = 1 volt, is connected; or, again if 10 volts that over 10,000 ohms or $\frac{1}{10}$ of the total, still 1 volt only is taken to the instrument. The instrument is, therefore, direct reading, unless, as in the case of current measurement, half values are taken and the reading doubled—a practice equally bad in this case, and for the same reasons, therefore, to be avoided.

"The true value to be assigned to the reading may be again somewhat puzzling to the unpractised, and is best got at by again noting the maximum reading obtainable from the terminals connected. One point only remembered, the rest is easy and no mistake is possible."

APPENDIX V.

FORM OF SPECIFICATION FOR THE WIRING OF FOR ELECTRIC LIGHT (OR FANS, &c.)

(1) *General conditions.*—The installation is to consist of all necessary cables, wire, casings, main distributing switchboards and fuseboards, switches, fuses, ceiling roses, wall plugs, &c., and the wiring of the building complete, in every detail and respect for [illegible] of electric light as arranged for in the following specification. The supply of electric energy will be from at an E. M. F. of volts. All materials must be of the best of their respective kinds and shall be applied in a substantial and workmanlike manner. The workmen employed to be [illegible] wiring and [illegible] work.

(2) *Defects to be made good.*—The contractors shall be responsible for any defects which may appear within 12 months from the taking over of the work due to defective workmanship [illegible] or any consequential damages arising therefrom and [illegible] on receiving notice of the same, are forthwith [illegible] to remedy such defects.

(3) The whole of the work shall be complete in every detail and ready to be [illegible] by and [illegible] in details of its [illegible] the work [illegible] in every respect [illegible] with the wiring rules of the Institution [illegible] those issued by the Electric Light [illegible] differs from them, the [illegible] must be followed.

(4) *Testing.*—[illegible] the work is in progress, and when completed [illegible] the whole work from earth with all fuses [illegible] at a pressure of [illegible] volts, shall [illegible] and the Supply Company [illegible].

(5) *[illegible] making good.*—The tender is to include any necessary [illegible] the wires in the walls, &c., also all necessary [illegible] walls and ceilings. The contractors will be held responsible for, and [illegible] any damage or disfigurement of the building which shall have been caused by the action of the contractors.

(6) *Position of lamps, &c.*—Accompanying this specification there are plans of the building on which are approximately shewn the position of the lamps and list of the lamps required for each room.

(7) *Wiring plans.*—After the contract is completed, the contractors must supply accurate and easily understood wiring plans of the whole installation, showing distinctly the course and size of every wire in the buildings, with the position of every lamp, fuse, switch or other thing belonging to the installation and the maximum current which every fuse is liable to carry.

(8) *Fittings.*—The contractors will have to fix and wire all fancy brackets, or other special fittings (but Government does not bind itself to purchase such through or from the contractors for the wiring). The tender is to $\frac{ex}{in}$clude all electroliers, brackets, portable lamps, ceiling and other special fittings, and also all lampholders, shades and flexible wires that may be required for the same but is to include together with the supply of lamps, ceiling roses and wall plugs.

The tubes of all fittings must be of such size as will enable them to be wired with the wires used for the general distribution, so that joints behind fittings may be avoided and where necessary they must be sufficiently large for more than two such wires to be carried in them in order that "looping back" may be freely resorted to for the exclusion of joints and, conversely, the wires used for wiring lamp-circuits must be of such size that they can be looped back from the lamp-holders without being reduced in size or number.

(9) *Conductors.*—The whole of the conductors throughout the buildings to be of tinned copper wire having a conductivity which shall in no case be less than 100 per cent. of Mathiessen's standard for pure copper. No wire of smaller size than No. 18 S.W.G. to be used. All conductors of a cross-section greater than No. 16 S.W.G. are to be stranded.

(10) *Insulation.*—All conductors shall be substantially and carefully insulated, with the very best pure and vulcanized India-rubber, and India-rubber-coated tape, properly protected externally by braided flax or cotton treated with a suitable and recognised preservative coating or by such other means as may be approved at the time the tenders are considered. The insulation resistance of conductors used must not in any case be less than 750 megohms per mile statute.

(11) *Current density.*—The sectional area of main and sub-main conductors of all sizes is to be so proportioned that they shall in no case carry a larger current than at the rate of (   ) ampères per square inch of copper. In estimating the current, lamps are to be rated as requiring $3\frac{1}{2}$ watts per candle-power, and as being of at least 16-C.-P in every case.

The potential difference between the conductors at the farthest or any lamp on the circuit, with all the lamps alight, shall not exceed 2 per cent. lower than at the main fuses.

(12) *Main switchboard.*—This shall be fixed in a convenient position in the building, and shall be provided with a voltmeter by which the E.M.F. (on both circuits)* may be read. The switchboard is to be provided with a good lock and key (and on or beyond it no circuits or wires having a greater difference of potential between them than 220 volts may be run within 6 feet of one another).* The mains from the switchboard to the . . . . . . fuse-box are to be included in the tender. The switchboard and this connecting main are to be suitable for . . . circuits (on the 3-wire system), each of . . . volts . . . ampères.

(13) *Joints.*—Joints are to be avoided as far as possible, and no joints whatever are to be made in any main cable or in any damp place. Where joints cannot be avoided, they shall be carefully made in the most approved manner, well soldered and vulcanised. Approved "connectors" may be used in place of joints in the ultimate lamp circuits, but they must be mounted on wood blocks and may not contain fuses.

(14) *Casing and capping.*—The whole of the mains, sub-mains, and lamp leads to be run as far as possible along the walls and ceilings, enclosed in proper casing so as to be easily accessible and capable of being thoroughly inspected. No wires may be run out of sight between walls and ceilings without special permission. Casing and capping shall be of well seasoned teakwood served before erection with two coats of shellac varnish internally and one coat of paint or varnish externally. The grooves to be rounded and the distance between them to be not less than $1\frac{1}{4}$ inches wide in the case of mains, 1 inch in that of sub-mains, and never less than $\frac{3}{4}$ inch in the smallest branch leads, care being taken to keep the middle fillet intact throughout. All joints shall be carefully mitred or overlapped in casing and capping, the latter to be moulded of approved design and specially arranged to be screwed on at the sides by means of round-headed brass screws. Where necessary, the walls must be well plugged to receive the casing, and after erection all visible casing is to be carefully painted to match the surroundings. Samples of casing and capping to be submitted with tender:

Provided that in place of casing an approved tube system may be employed throughout.

(15) Where cables or wires pass through walls, they shall be carried in such manner as may be directed by the Electrical Engineer.

(16) The wiring must be done on the distribution system, with main and branch distributing boards at convenient centres, and the circuits from the branch distributing boards must not supply more than 550 watts. The distributing boards must be constructed of incombustible material, preferably with front connections, with circuits arranged as far as possible to form their own diagram of connections, and so labelled that they may be easily identified. Exposed metal parts of different polarity must be separated by an insulating and incombustible partition, or else separately mounted on different bases. All

* This is in the case of 2 × 220 volt 3-wire installations.

fuses to be of such section that they will carry 50 per cent. over and melt with approximately 75 per cent. over the normal current and to be of a standard non-interchangeable pattern as far as possible. Isolated cut-outs in inaccesible situations must not be used. All main and circuit fuses throughout the installations must be provided with reference number or letter by means of which the circuits they control can easily be found on the wiring plan.

(17) *Switch blocks*—The switches for controlling the lamps in each room will be mounted on polished teak blocks with neat moulding round the edge. These will be fixed in convenient approved positions in the rooms. The positions of these, as well as the runs of casings, must be settled before the work is commenced in consultation with the Electrical Engineer.

(18) *Ceiling roses.*—Ceiling roses must be porcelain with no back connections. They must be mounted on polished teak blocks, and are not to contain fuse terminals.

(19) *Switches.*—The bases of switches must be of porcelain with no back connections. They are to be of quick-break (high-voltage) type, covers to be incombustible, and all parts of the switch carrying current to be insulated from the handle.

(20) *Cut-outs and wall sockets.*—These are to be of a design suitable for . . . . volts.

(21) *Lamps.*—To be suitable for an E. M. F. of . . . . volts and an efficiency of $3\frac{1}{2}$ watts per candle approximately, and to be of the candle-power laid down in the schedules. All lamps in ceiling fittings are to be frosted, the rest to be clear glass.

ELECTRIC LIGHTING FORMS.

No. 1.—Form of Schedule.

Number of room.	Description.	Circuit Number. Main.	Circuit Number. Branch.	Number of— Fittings.	Number of— Lights per fitting.	If adapted.	Description of fitting.	Candle-power		16	8	Total lamps.	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14

No. 2.—Form of Summary of Lights

Position.	32 candle-power.	16 candle-power.	8 candle-power.	5 candle-power.	Total.	
1	2	3	4	5	6	7
Ground floor						
First floor						
Second floor						
Grounds						
Stables						
&c.						
&c.						
&c.						
Total ...						Grand Total.
Equivalent in 8-candle-power lamps.						Total equivalent, 8-candle-power lamps.

No. 3.—Form of Summary of Fittings.

Position.	Ceiling fixtures.				Brackets.		Pendants.	Wall sockets for portable lamps.	Electroliers.	Total.
	One light.	Two lights.	Three lights.	Four lights.	One light.	Two lights.				
1	2	3	4	5	6	7	8	9	10	11
Ground floor										
First floor										
Second floor . .										
Grounds										
Stables										
&c.										
&c.										
Total ...										Grand Total.

E. J H.– Reg. No. 4946J—350—19·7·1900.

LECTURES
ON
ELECTRICAL ENGINEERING
WITH PARTICULAR REFERENCE TO
CONDITIONS IN BENGAL.

LECTURE I.

INTRODUCTORY.

IT will be at once apparent to you that in a course of six lectures on the subject which has been selected this year, it would be impossible to more than touch the fringe of many subjects that come within the scope of an electrical engineer's work, should the lecturer attempt to deal with the science in all its ramifications. This would not fulfil the main object of this annual course, and it will be evidently of far greater value to you if I choose the particular branches that you may be called upon to work in, and give you some practical remarks with regard to each in turn.

And here let me say that at the present day it is in no wise sufficient to make a deep study of one branch of engineering unless you have some knowledge of other allied ones. Those of you who may take up electrical engineering as a profession will find at every turn the value of what you have learnt of civil, mechanical and hydraulic engineering, chemistry and physics, and, above all, workshop practice; while those who throw their lot into one of these other branches of science or engineering will sooner or later, I am sure, be thankful that they have learnt enough of electrical work to help them when necessity arises. It is said, with perfect truth as regards many matters, that "a little knowledge is a dangerous thing," but there is no doubt in my mind that even a little knowledge—provided it be sound knowledge—of allied sciences is of the very greatest value to engineers of all sorts. Of course one particular branch only can be taken up as a profession if the student is to become really proficient, the others being merely adjuncts, and I may go further and say that it is impossible during the period one is under training even to master one branch in all its intricacies. A specialist in one subdivision will generally succeed better than one who attempts too much. I may remind you of the story of the coleopterist, of whom it was remarked: "If he had only confined his researches to one species of beetle, he might have been famous."

Applications of electricity.—Now let us enumerate briefly the chief applications of electrical energy or, shortly, electricity—

(1) Obviously it is as a means of giving light that the majority of people regard it, seeing that this is the commonest and most evident use to which it can be put. Street-lighting, either by arc lamps—as in Harrison Road, Calcutta—or by incandescent lamps—as in Darjeeling; factory lighting, and house or public building lighting come under this head. Examples of all these are found in and around Calcutta, and as time goes on, other cities in Bengal will no doubt follow suit.

(2) Secondly, there is the application of electricity for the purpose of giving power through electromotors. This head includes the driving of tram-cars and automobile vehicles, of machinery in factories, workshops and mines, and of small-power motors for domestic uses, such as the working of rotary fans, punkah-pulling or sewing machines and the like. It is more than probable that we shall presently have electric tramways working in this district, and already during the last hot weather a very considerable number of rotary electric fans have been at work. With the advent of a good electrical punkah-pulling machine it may be safely predicted that the annoyance due to the present unsatisfactory methods will become a thing of the past.

(3) Thirdly, in order of importance to mankind comes, I think, the direct use of electricity in manufacturing operations, electro-chemical and electro-metallurgical. Not least among these come the process of electroplating and of the electro-deposition of metals—in some cases the surest and almost only way of obtaining chemical purity in the products. In the arts, also, electro-deposition has a wide application in the various electrical reproducing processes, by which casts, medals and the like can be reproduced with the utmost exactitude. Among the most important products of electro-metallurgy is aluminium, the manifold uses of which are now fully recognised. Though amongst the very commonest elements in the earth's crust, it is one of the most difficult to reduce, and only since the electrical process was evolved has the price become in any way reasonable. It is a product of the electric furnace, one of the most powerful agents known, by means of which a temperature previously undreamt of can be obtained and maintained throughout a large mass of material. Through the same agency phosphorus is now being manufactured on a large scale, and an altogether new material called carborundum is now being manufactured in America as a substitute for emery, than which it has far greater powers of attrition. I may mention, in passing, that by means of the electric furnace true diamonds of very small size have also been successfully made in the laboratory. Among electro-chemical products chlorate of potash is perhaps the

most important, and is electrolytically manufactured in competition with the older methods. Sanitary science is also being benefited by various systems for the electrolytic purification of sewage now under trial.

(4) Fourthly, there is the use of electricity for moderate heating purposes as distinct from the electric furnace. Wherever electric power is installed, electric heating can be called into play in various ways. Thus in cold countries tram-cars are generally heated during the cold months, and, to a certain extent, the same may be said of houses and public buildings, though in the latter case it probably does not pay to substitute electric radiators for coal or wood fires. Indeed, apart from the question of cost, most people prefer the open fire owing to its cheerful appearance. Again, there is a considerable utilization of small domestic apparatus, such as electric hot plates, kettles and ovens, which, though certainly expensive luxuries, are beyond doubt a great convenience in certain cases owing to their cleanliness and readiness at short notice.

(5) There are other applications of electricity of boundless importance to mankind which do not, however, come within the scope of the ordinary electrical engineer's work, and have therefore been relegated by me to a back place. The enormous development of telegraphy and telephony in all their different forms, and in a lesser, though still important, degree the uses of electric bells, electric firing of mines, Rontgen-ray work, and electro-therapeutics bear witness to this.

From this summary you will see how vast and far-reaching an effect the electric current has had on the affairs of the world.

Generation of electricity.—For any or all of these purposes electricity may be derived from one of several different sources. The simplest of these is the primary battery, consisting, generally speaking, of plates of two dissimilar metals in an electrolyte capable of chemically acting upon one of them. Its use is almost restricted to giving the necessary power for one of these last-named applications wherein very small currents only are utilized, and we need therefore do no more than notice their existence in passing. The thermopile also need not occupy much of our time; in this form of generator the current is obtained by means of alternately heating and cooling the junctions between certain dissimilar metals. Though apparently a solution of the problem of obtaining electricity direct from coal, it leaves very much to be desired in the way of efficiency and convenience. The most general method is to obtain the power from fuel—coal, wood, oil or gas—through the agency of an engine and dynamo. Sometimes a separate private plant is maintained for the supply of a particular installation; in other cases power is generated in a large station in the centre of a town and thence distributed through a net-work of conductors to all who may wish to use it, while, again, there have recently been proposals to establish such stations at the coal-fields, where fuel is at its cheapest, and then distribute the power over a large tract of country to wherever a demand arises.

Then, again, electric power may be obtained from falling water through the agency of a turbine and dynamo. This source of electricity is of very great importance in places where suitable conditions are found, especially if fuel at the same time is expensive, since it often pays to bring the power from many miles distant rather than generate it on the spot by the consumption of fuel. And by no other agency than this can power be economically transmitted over very long distances; wire-rope transmission of power has its practical limit of a few miles, and no other system can compete on terms of equality.

There is one great advantage that gas has over electricity—I mean the fact that it is a material substance capable of being stored in any quantity. Electricity must be generated at the instant it is to be used, and cannot be stored. This statement sounds ridiculous in the face of the fact that one constantly hears of 'storage batteries' and 'accumulators,' but these store electricity only in the sense that coal may be said to store heat, and in no wise like a gasholder stores gas. Coal contains a certain amount of latent energy in the form of carbon and hydrocarbons, capable of being released as heat under suitable conditions. And the charged plates of a secondary battery contain latent energy also, bound up in the chemical condition of the plates, but capable of rapid release in the changed form of electrical energy under certain circumstances.

Fundamental and derived units.—The ground I propose to traverse in these lectures will be mainly confined to the question of electric lighting in houses and the supply of energy for that purpose, and, having said this much by way of introduction, we will now pass on to consider and define the physical quantities dealt with in electrical work and the practical evolved units by which they are denoted and measured. It is not, I think, necessary that I should explain to you in great detail the origin of the fundamental electrical units, as my aim will be to impart practical rather than theoretical information, but a few words may be said on the subject with advantage. The French or metric system of weights and measures is what is known as an absolute system, wherein all units are simply derived from the fundamental conceptions of length, mass and time. In addition to this simple relation between its units, the system has also a great advantage over many other systems of weights and measures - the Indian being no exception—in that all multiples and fractions are on the decimal principle. These facts induced scientific men everywhere to agree to the metric system as the basis of the present 'absolute' electrical units, and in this connection the name of the C. G. S , or centimetre-gramme-second system has arisen. I will give you some short definitions of the chief physical units derived from these three fundamental ones, leaving you to study the subject at your leisure in the text-books.

Velocity is the rate of change of position along any path, and the unit is a speed of one centimetre per second.

Acceleration is the rate of change of velocity, the unit being a change of speed of one centimetre per second, either positive or negative.

Force is that which produces acceleration, and the unit of force or *dyne* is such that when acting on a mass of one gramme for one second it produces an acceleration of one centimetre per second. The force of gravity is roughly 980 dynes.

Work is the result of the displacement of mass against force. The unit or *erg* is the force expended in displacement through one centimetre against a force of one dyne. If one gramme is lifted against gravity, therefore 980 ergs of work are done. The unit represents such a small amount of work that an auxiliary unit called the *joule* is frequently used, equivalent to 10 million ergs.

Activity is the rate of doing work, and the unit of activity is a rate of 1 erg per second. For the same reason as in the case of work, a larger unit of 10 million ergs (or one joule) per second is called one *watt*.

I need not, I think, tell you elementary facts about magnets, magnetism and electricity, since you will have learnt these from your text-books, but we will pass on to consider the electrical units. In order to trace their connection with the fundamental units of length, mass and time, we will start with the definition of a unit magnetic pole, from which the practical units are derived. If we have two thin magnets, of such length that when two poles are brought near together the other two are far enough off to exert no appreciable influence, and the adjoining poles are of such strength that at a distance of one centimetre apart they attract one another with a force of one dyne, then each is said to be a unit pole. You are aware of the effect of passing an electric current through a wire in causing attraction to a magnetic needle in its neighbourhood, and the unit of current is obtained from consideration of this effect. A unit current is such that one centimetre length of it (*i.e.*, of the wire carrying it) acts on a unit magnetic pole with a force of one dyne, every part of the wire being one centimetre distant radially from the pole. The *ampère*—which is one-tenth part of this C. G. S. unit—is the practical unit of current strength and represents a certain rate of delivery of electricity in just the same way that so many gallons per minute does in the case of water. An ampère is a current such that, when passed through a solution of nitrate of silver of certain strength, it deposits silver at the rate of ·001118 gramme per second.

The quantity of electricity delivered in one second by a current of one ampère is called one *coulomb*, but this is a term you will seldom hear used.

The practical unit of difference of electrical potential is the *volt*, and is 100,000,000 times the C. G. S. unit. In order to gain a clear conception of what it is, we may advantageously make use of the analogy of water. Difference of potential corresponds with 'head' in hydrostatics, and just as water tends to flow from a higher place to a lower one in consequence of, and proportionally to, the difference of level between them, so does electricity tend to flow from a point of higher electrical potential to one of lower; and a current of electricity will never flow in a conductor unless there is a difference of electrical potential between its terminal points. And as in a pumping-station the flow of water upwards against a certain head is caused by the pressure behind it, so a current of electricity in a conductor is due to a difference of potential caused by the pressure or *electromotive force* acting on it. Again, just as the higher of two connected bodies of water can be determined by the direction of flow between them, so can the points of higher potential in a conductor be determined by the direction of the current flowing between them.

A volt is just about the electromotive force—or E.M.F.—of a single Daniell cell, but the practical standard used for testing purposes is obtained by comparison with the 'Clark standard cell,' of which I shall tell you later on when dealing with the potentiometer. I need hardly tell you that under equal conditions of pressure or head a large water-pipe will convey a greater number of gallons per minute than a small one; the fact is self-evident. But since electricity is not a material substance, it is always a point of difficulty to many people that a given wire should only be reckoned on to carry a certain current under given conditions. As the flow of water is restricted by the size of the pipes carrying it, and by the resistance of any unevenness in the metal or any obstruction in the bore, so is the flow of electricity impeded by the *resistance* of the wire that carries it. Theoretically resistance is regarded in the C. G. S. system as a velocity, for reasons with which, however, I do not intend to trouble you. Practically it is simpler to regard it as that inherent quality in any substance owing to which the free passage of electricity is prevented, so that a given pressure or E.M.F. can only cause a certain current to flow. And, fortunately, there is a very simple relation between resistance and the two previously explained units. For if a steady current flows in a conductor and the difference of potential between any two points on it is measured, it is found that the quotient of the difference of potential in volts, divided by the current in ampères, is independent of the strength of the current, though varying with the physical nature of the conductor. If the current is doubled, the difference of potential is doubled, and if the current is halved, the difference of potential is halved—provided that the temperature of the conductor is constant. There is, therefore, a certain resistance to the flow of current which is found to represent the ratio between pressure and consequent flow. If in a given conductor a current of one ampère is flowing, and two points are taken such that the difference of potential between them is one volt, then the resistance of that length of the conductor is the practical unit, one *ohm*. The ratio may then be expressed thus; volts ÷ ampères = ohms. I need only mention, in passing, that the ohm is 10^9, or 1,000,000,000 times as great as the absolute C.G.S. unit of resistance.

The standard ohm is represented by the resistance of a uniform column of mercury 106·3 centimetres long and 14·452 grammes in mass at 0°C., but the actual standard is a coil of wire in the possession of the English 'Board of Trade,' by comparison with which other 'standard ohm' coils are made. The resistance of any conductor is a quantity which depends only on its dimensions, shape and physical conditions, and not at all on the strength of the current passing through it, except in so far as this may alter or modify these latter. It varies directly as the length, and inversely as the cross-sectional area of the conductor, and for any given material, therefore, the calculations of the relative resistance of different lengths and sizes are simple enough.

To compare the relative resistances of different materials we must have some standard or 'specific resistance' to go by, and it is defined as the resistance of a cubic centimetre of any material at a temperature

of 0°C. to a current passing between opposed planes or faces. If the specific resistance in ohms of any substance is known, and it is required to find out the actual resistance of a given piece of it, we must evidently multiply the specific resistance by the length in centimetres and divide by the cross sectional area in square centimetres.

The specific resistance of pure copper is ·000,001,59 ohms, and this is the material, as you know, used for most electrical work, owing to its great conducting power. Silver alone has a fractionally higher conductivity than copper, but its price naturally puts it out of the field of competition. I should have mentioned that conductivity is the reciprocal of resistance, so that the lower the specific resistance of a material the better its conductivity.

The only metal that competes with copper for conducting purposes is aluminium, which I told you just now is becoming cheap owing to its production in the electric furnace. It is a fair conductor, having a specific conductivity of about 55 per cent. of that of pure copper, and it has a very low specific gravity, so that, weight for weight, it has a current-carrying capacity about 1·8 times that of copper. But it has two disadvantages: firstly, large bulk, which prevents its being used much in coils, and, secondly, large surface, which is exposed to wind pressure in the case of overhead lines.

Not always, however, do we require the best conductor in electrical work, and other metals are largely used in order to purposely introduce resistance when desirable. We shall deal more fully with resistances later on. Taking copper as the standard, the following list gives the specific resistance of some of the chief metals used in electrical work relative to it, *i.e.*, given a certain length of pure copper wire of any gauge, its resistance multiplied by the figures below will give the resistances of exactly similar pieces of the metals named—

Aluminium	1·82
Iron	5·95
Tin	8·c9
Lead	12·13
German silver	12·85
Platinoid	19·5

Speaking generally, the metals are good conductors of electricity as distinct from so called insulators, though actually bad conductors merge insensibly into bad insulators, leaving no hard-and fast division line. Glass, porcelain, India-rubber and dry wood are examples of good insulators, but the latter, if damp, may become a conductor to no inconsiderable extent.

We will next consider the question of work or energy from the electrical standpoint. The practical unit is the joule (10 million ergs), which is the amount of work done in one second by one ampère under a difference of potential of one volt, *i.e.*, one coulomb volt. In dealing with large machinery, even this unit represents far too small an amount of work, and it is more generally convenient to use the 'Board of Trade unit' of 3,600,000 joules, or 1·34 horse-power hours.

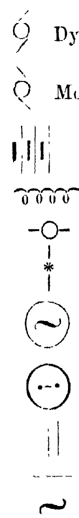
If a current of 10 ampères is passed through a conductor under a pressure of 100 volts, then one B. O. T. unit of work is done

in an hour, *i.e.*, 1,000 volt-ampère hours. You can calculate for yourself the number of fundamental 'ergs' this represents.

Power or activity is measured in *watts*, a watt being the rate of work done by one ampère under an electromotive force of one volt, or one volt-ampère. This is a unit in constant use in our profession, and you should commit to memory—if you have not already done so—the fact that 746 watts are equivalent to a rate of one horse-power. A power of 1,000 watts is called a killowatt, and this word is generally used to express the power a dynamo is capable of delivering. You will at once see from what I have just told you that a B. O. T. unit of work is one killowatt hour; it is generally called simply a *unit* in electrical supply, the price of a unit in Calcutta, for instance, varying from 5 to 8 annas. It is not unusual to hear a dynamo spoken of as a 10- or 20-unit machine. This is an incorrect use of the term, kilowatt being intended and not kilowatt-hour.

The mere explanation of these units does not bring familiarity in its train, and indeed nothing but practical work with electrical machinery gives life to such dry bones. But you, of course, have the opportunity in this College of becoming familiar with the working of such machinery and no doubt make good use of it.

Explanation of terms in common use.—I think I need not trouble you with definitions of any other units at present, but there are certain technical terms in common use which it is necessary for you to thoroughly understand, and in order to simplify the diagrams to be presently shewn you, I give you a list of some of the conventional signs which are used to represent various electrical terms or pieces of apparatus—



Dynamo } Continuous current.
Motor }

Battery. (The thick lines are the positive plates.)

, or WW Coil of wire.

Incandescent lamp.

Arc lamp.

Switch.

Fusible cut-out.

Arranged in parallel.

" " series.

Period of an alternating current.

The term 'circuit' is applied to any arrangement of conductors and apparatus intended to carry an electric current. Thus to take a

simple example I give you a diagram of an electric bell, with a battery and push or pressel (Fig. 1). Here the circuit runs from the battery

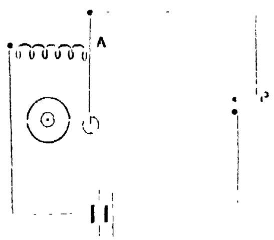


Fig. 1.

through the wires to the bell through the coil of wire and the contact-breaker A, and then on to the push P, from the other terminal of which it goes back to the battery. Here, when the bell is not ringing, there is a break in the continuity; this as it stands is called an 'open circuit,' since it is broken or opened at the push, the pressing of which will give us apparently a 'closed circuit.' But when we close the circuit and the bell begins to ring, a new state of affairs is introduced, since the contact-breaker comes into action at every stroke and gives us an 'intermittent circuit.'

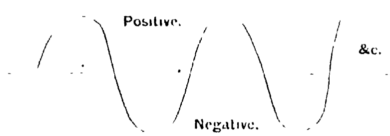
When a current passes through an apparatus in this way the result is an 'intermittent current' in the form of short waves with a distinct break between each lasting for an appreciable time.

With certain forms of apparatus an 'interrupted current' is obtained, in the form of periodic waves starting from zero, rising to a maximum, falling again to zero, and instantly starting to rise again, so that only an infinitely short break occurs. This is graphically shown in the diagram—

Line of zero potential.

Fig. 2.

Again, we may have an 'alternating current,' which is in the form of periodic waves starting from zero, rising to a maximum value in one direction, falling back to zero and then rising to a maximum value in the opposite direction, and so forth—



Line of zero protential.

Fig 3

The alternations are generally very rapid, from 50 complete cycles (or 50 ~) per second upwards, but nevertheless if the circuit is

broken by a switch, it may by chance happen just at that instant when the current-wave is crossing the zero line, in which case no spark or sign of breaking a current would occur, even though many lamps were thereby extinguished.

The most usual form in which electricity is used is the 'continuous current,' such as is given by a battery in action. This would be represented graphically by a straight line.

An ordinary 'direct-current' dynamo is said to generate a continuous current, though this is not absolutely true. A number of separate interrupted currents are generated, and their joint effect becomes practically continuous through overlapping, as you will see from the diagrams below (Figs. 4, 5)—

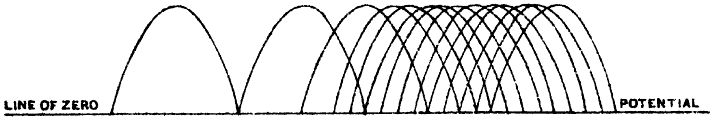


Fig. 4.

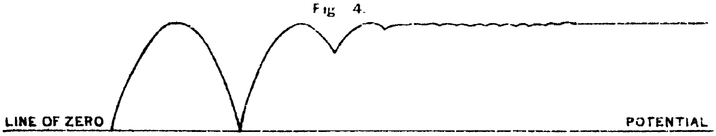


Fig. 5

We now come to the question as to the absolute direction of flow in a conductor. It is easy to determine the relative directions, but it is doubtful whether we can tell the real direction at all; in fact, the assumption of that knowledge is merely a very necessary conventionality. It is convenient to say that the current in a conductor flows from the positive (or +) pole of the source of power to the negative (or —) pole. If we know which pole is positive, then the conventional direction of flow is predetermined; and if, on the other hand, we have a current flowing, the simplest instruments will give us its conventional direction and identify the poles.

If our current is being used in an incandescent lamp it matters nothing what direction it is travelling in; a certain rate of watts will keep the temperature of the filament at the required heat. But if it is being used for electroplating (for instance) it makes all the difference in the world, since the reversal of the direction of the current would cause the silver already deposited to be removed and deposited back on to the piece from which it came.

Let us suppose we have several conductors, A, B, C, just alike in all respects electrically. If we join two of them up, so as to make one double length, they are said to be in 'series.' (They need not of course

Fig. 6.

be straight; the same thing applies to coils.) It is then fairly evident that the resistance of the whole piece is double that of either of the original pieces.

But we can also put them side by side and join the two ends of each together, respectively (Fig. 7).

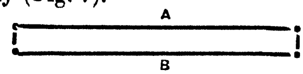


Fig. 7.

We then have a conductor of the original length, but of double the cross-sectional area. Here you will see that the combined resistance will be half that of either piece by itself and one-fourth that of the two in series. This is called coupling them in 'parallel.' If we take three pieces instead of two, the resistances would in the same way be three times and one-third that of an original piece.

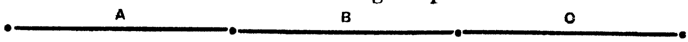


Fig. 8.

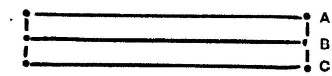


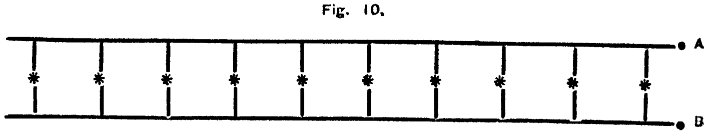
Fig. 9.

Now let us take it that our conductors are of different resistances, say four, measuring 2, 4, 5 and 11 ohms. If they are joined in series the combined resistance is still the sum of the separate ones, each piece offering its original resistance in turn to the current. But if we place them in parallel we have to adopt a more complicated procedure in order to find the combined resistance. Since each extra conductor reduces the resistance it increases the reciprocal quantity—conductivity. So we have to obtain the combined conductivity by adding the reciprocals of all the resistances together thus: $\frac{1}{2} \times \frac{1}{4} \times \frac{1}{5} \times \frac{1}{11} = \frac{229}{220}$, and then the reciprocal of this quantity gives the combined resistance $\frac{220}{229}$, or ·96 ohms.

We will take some practical examples now of series and parallel circuits. Suppose we have 10 lamps of such construction that each requires an E. M. F. of 100 volts across its terminals, in order that it may obtain its full working current of 5 ampères. Now we can connect these lamps either in series or in parallel in the way shewn in

10 lamps series.

Fig. 10.



10 lamps parallel.

Fig. 11.

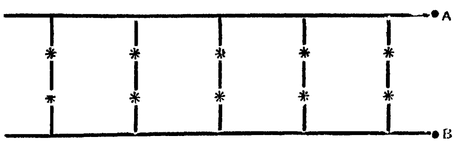
the figures where (Figs. 10, 11) A, B are the terminals at which the current enters and leaves.

In the first or series case there is only one path for the current, and that takes it right through every lamp in succession. But as every lamp offers such a resistance to the passage of the current that it requires 100

volts to overcome it, we see that our source of power must give a current of 5 ampères at a difference of potential of 100 x 10, or 1,000 volts. The power developed will then be 5 x 1,000, or 5,000 watts.

Now in the second instance, where the lamps are in parallel between two conductors, there are 10 paths open to the current, each separate path requiring 5 ampères. If a difference of potential of 100 volts is maintained between the two parallel wires, we shall have the required condition of things, since there will then be 100 volts E.M.F. at the terminals of every lamp. So here our source of power must give 5 x 10, or 50 ampères at 100 volts, and the power will, as before, be 5,000 watts (50 x 100), which is precisely what we should expect, remembering that we have the very same number of lamps alight.

A combination of series and parallel circuits is not unusual. Thus our 10 lamps might be connected as shown in Fig. 12, in which case

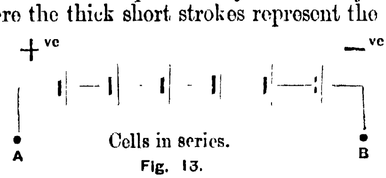


10 lamps, 2 in series

Fig. 12

we should require an E.M.F. of 200 volts to force the current through 2 lamps in series, and a current of 25 ampères for the 5 groups of 5 ampères each; this is called running "two in series over 200 volts."

In primary batteries, wherein the energy is generally produced by the oxidation of zinc, this metal is the positive pole from which the current flows through the external circuit to the other pole, of the battery, and thence through the electrolyte (or internal circuit) back to the zinc. If we require more energy than one cell is capable of giving, we must connect several together and so get their joint power. This may be done either by connecting them in series or in parallel according to the needs of the case. If one cell gives sufficient current, but a higher electromotive force is required, they must be joined in series as in figure 13—where the thick short strokes represent the zinc or positive



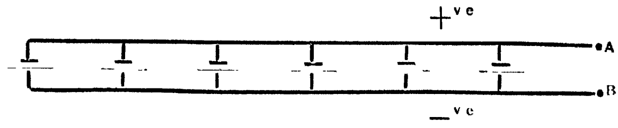
Cells in series.

Fig. 13.

pole and the long, thin ones the negative pole (generally carbon). You will notice that the positive pole of one cell is connected to the negative of the next all through. This leaves a positive pole vacant at one end and a negative at the other, to which points A, B, the external circuit is connected. The difference of potential between these poles is the sum of the E. M. F.'s of all the cells. If one cell were accidentally connected up with its poles the wrong way as regards the rest, then not only would its E.M.F. not be

added to the others, but it would also oppose them actively, and thus make a difference to the circuit of twice its E.M.F.

Now suppose we require a large current and are content with the E.M F. of one cell only, and we must connect up in parallel (Fig. 14).

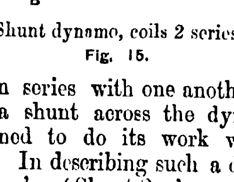


Cells in parallel.
Fig. 14.

In this instance all the separate positive plates must be joined together and all the separate negative plates. The effect of this is that the combination becomes really one large cell whose E.M.F. remains that of a single cell. But owing to the reduction of internal resistance that E. M. F. is able to produce a proportionately greater external current.

I should perhaps say a word or two about 'internal resistance.' In dealing with power generated by a battery the E.M.F. has to overcome not only the resistance of the external circuit, but also that of the cells themselves; this is partly due to the electrolyte, or liquid, and partly also in many cases to a 'porous pot' which divides the cell into two compartments. This consists of a form of terra-cotta, in itself practically an insulator, but offering a passage to the current through the liquid contained in its pores.

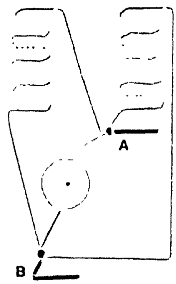
I need not enumerate to you the component parts of a dynamo, but it is essential that you should have a clear understanding of the terms 'shunt' and 'series' as applied to their field coils. A shunt, as the name shews, offers an alternative path for some of the current; thus in a shunt-wound dynamo there are two paths open from the terminals A B—one through the external circuit and the other through the shunt coils. Note that the two shunt coils in this



Shunt dynamo, coils 2 series.
Fig. 15.

diagram (Fig. 15) are in series with one another, but that the whole double length coil is a shunt across the dynamo terminals. Each coil is therefore designed to do its work when half the terminal E.M.F. is acting on it. In describing such a dynamo one would say 'Shunt coupled two series,' or 'Shunt 2—'.

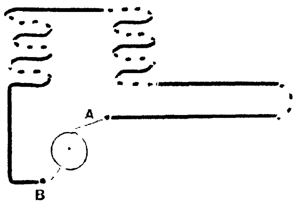
It is sometimes more convenient to couple the two shunt coils quite independently, each across the machine terminals and therefore in parallel with one another (Fig. 16).



Shunt dynamo, coils 2 parallel.
Fig. 16.

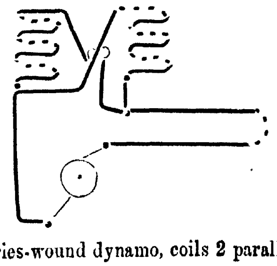
If you have to couple a shunt machine up and are in doubt which way it is intended to be done, always try the coils in series first, and if wrong no damage will be done, since the current will be only half what is intended. On the other hand, if you put the coils in parallel when they should be in series, you get four times the proper current and burn the coils up, apart from other considerations!

In a series-wound dynamo (Fig. 17) there is but one path for the current, the whole of which passes in succession through the field coils and the external circuit, unless it happens to be more convenient



Series-wound dynamo, coils 2 series.
Fig. 17.

to couple the coils themselves in parallel, when half the current passes through each coil (Fig. 18).

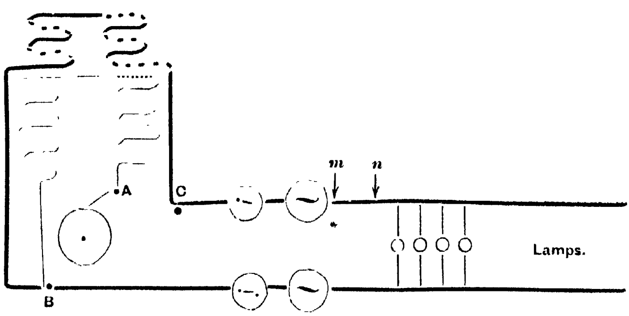


Series-wound dynamo, coils 2 parallel.
Fig. 18.

A compound wound dynamo has both series and shunt coils superimposed on the magnets, and therefore both must be taken into consideration. The coupling of it may be any combination of the types shown in the above diagrams, and the series coils are here generally known as the 'Main,' since the main (or external) current goes through them. A diagram of a compound wound dynamo will be shown presently (Fig. 19).

Ohm's law.—In explaining the term and unit of resistance to you just now I pointed out the constant relations between volts, ampères and ohms. This relation is embodied in Ohm's law, which expresses the fact that "the current varies directly as the electromotive force and inversely as the resistance." It is usually written $C = \frac{E}{R}$, where C. stands for current, E. for electromotive force and R. for resistance, and of course the equation stands equally well as $R = \frac{E}{C}$, or $E = C.R.$ This invaluable law makes the majority of ordinary electrical calculations very simple, since given any two quantities the third is found by simple multiplication or division. I say the *majority* of calculations advisedly, for the wrong application of the law has led many people into grave errors.

Now let us take an example of a simple electrical circuit (Fig. 19) in which a compound wound dynamo, capable of giving 48 ampères at an E. M. F. of 100 volts at the terminals, supplies current to incandescent lamps in parallel. (I have taken a dynamo of which I calculated the windings myself some years ago, and consequently I have full particulars of it in my note-books.) If the switch is open, or the



Compound wound dynamo supplying lamps.
Fig. 19.

fuses in the cut-outs have melted, the external circuit is open even though the dynamo brushes are down. In that case the only current used will be that passing through the shunt coils, and the dynamo magnets are said to be 'excited.'

Supposing, however, the circuit is closed and everything in working order, we can study our units practically. First dealing with the external circuit, let us suppose that its total resistance

at a given time is 50 ohms. Then by Ohm's law the current $= \frac{100v.}{50\omega.}$, or 2 ampères; this resistance has therefore absorbed 100 volts in forcing that current through the lamps and wires. Consider now one part of the circuit only, say the piece of wire from *m* to *n*. If the resistance of that piece is ·2 of an ohm, then our rule will give us the proportion of the 100 volts which is absorbed between those points. For since $E = C \times R$, the volts lost are equal to $2 \times \cdot 2$ or ·4 volt, and this figure will rise in proportion as more current is transmitted through the wire. Now on this circuit the lamps would be of such design as to give a certain definite candle-power when a pressure of 100 volts is applied *at their own terminals*. If therefore the wires absorb (say) 5 volts on their own account the lamp will only get 95 volts and will not therefore give its full brightness; hence we see the necessity of keeping the resistance of the wires and connections within small and reasonable limits, so that when the full current is passing they may not absorb too much power. I shall return to this point in detail later on.

The most common—and natural—error to make with regard to Ohm's law is perhaps the following:—As our dynamo is marked to give an output of 100 volts and 48 ampères, people will ask if the resistance of the dynamo is not $\frac{100}{48}$, or 2·08 ohms. This is due to a misconception, for a dynamo cannot be said to have any total resistance, though each separate part has its own. The above figures are the output in the external circuit, and give the resistance of that circuit at full load—when the 100 volts are generating 48 ampères. I may appear to you to have here contradicted my previous statement that the resistance of a circuit does not depend on the current passing through it, but of course the two cases are not the same. In the above instance, when the resistance of the circuit was 50 ohms there would only be about three 16 candle-power lamps alight, whereas with 48 ampères there would be some 75 lamps in parallel. At full load the power being absorbed in the external circuit is 48·v. × 100·a., that is to say at the rate of 4,800 watts or 4·8 kilowatts. Dividing by 746, the figure I have already given you, we find that is equivalent to 6·4 horse-power. Also the total amount of external work done in one hour will be 4,800 watt hours, or 4·8 Board-of-Trade units.

Next let us take the armature of the dynamo. Its resistance under full working conditions of temperature is ·07 ohm, and therefore when 48 ampères are being generated there is a drop of ·07 ω × 48 a., or 3·4 volts. These are known as the "lost volts" in the armature, since they are generated but do not give any useful effect at the lamps, nor are they shown on the voltmeter; they have to be taken into account, however, as we shall see. The power wasted in the armature is 3·4 v. × 48a., or 163 watts.

Taking the field magnet coils we have two separate calculations to make—the main (or series) and the shunt coils. The main coils were coupled in series, the total resistance being ·04 ohm. The main current passing through these coils will cause a drop of 48·a. × ·04ω. or 1·9 volts, the power wasted amounting to 1·9v. × 48·a., or 91 watts

Returning to the lost volts we can now find the actual E.M.F. generated in the armature—

External circuit	... ...	100· volts.
Loss in armature	... ...	3·4 „
„ main coils	... ...	1·9 „
Armature E. M. F.	...	105·3 „

Lastly, the shunt coils were also coupled in series and had a total resistance of 25·2 ohms. The full E.M.F. of 100 volts is applied to this (for the ends of the shunt are coupled to the brushes of the machine), and the shunt current is therefore $\frac{100}{25 \cdot 2}$, or 3·98 ampères. The power absorbed is at the rate of $100 \cdot \times 3{\cdot}98 = 398 \cdot$ watts.

What happens to all this—so to speak—waste power? It is converted into heat in the conductors and is dissipated in the air. And this brings me to the ordinary method of calculating the watts so lost in any circuit. It is just as simple and often far more convenient than taking the product of the current and the volts—

$$\text{By Ohm's law } E = C \times R.$$
$$\text{Now watts} = E. \times C.$$
$$= C.\ R \times C.$$
$$= C^2\ R.$$

So if we square the current and multiply the result by the resistance, we get just the same figures as before. It is a common practice to call the power used in conductors the 'C^2 R.' watts or losses.

This completes the calculations of the losses in the conductors of the dynamo or 'copper losses,' and we will now summarise our results—

Losses in armature	3·4 v. × 48·a.	or $(48)^2 \times {\cdot}07$	= 163 watts.
„ „ main coils	1·9 v. × 48·a.	or $(48)^2 \times {\cdot}04$	= 91 „
„ „ shunt „	100· v. × 3·98a.	or $(3{\cdot}98)^2 \times 25{\cdot}2$	= 398 „
	Total copper losses ...		652 „

Now we have all the figures necessary to obtain the 'electrical efficiency' of our dynamo which $= \frac{\text{Output watts}}{\text{Output watts} + \text{copper losses}} = \frac{4800}{4800+652} = \frac{4800}{5452}$ or just over 90 per cent.

To obtain the 'commercial efficiency' we must take into account the watts lost in 'hysteresis' in the iron core—due to the iron not losing its magnetism instantly, and consequently having to be demagnetised by the current at each reversal—friction of the moving parts in the bearings, windage and stray 'eddy currents.' The hysterisis watts amounted by calculation to 120; I have no record of the remaining ones, but think we may take them at about 350 watts. This adds an extra 470 to our denominator and makes the commercial efficiency $\frac{4800}{5922}$ or 81⅓ per cent.

LECTURE II.

MATERIALS USED IN ELECTRIC LIGHTING.

I INTEND in this second lecture to deal not so much with electric currents as with the apparatus for carrying, controlling and using them in houses so that you may learn to know what to use in any given instance; for we meet with a great number of different conditions in electrical work, and what is sauce for the goose is often by no means so for the gander. When electric lighting first came into use the nearest man who ran bell wires was sent for, and he put up wires of the same sort and in the same way with (generally) most unsatisfactory results. It has recently become a very general practice to use a pressure of 220 volts at the lamps in place of 110 or 100 volts; the company who supply Calcutta are using this pressure, and so are the Darjeeling Municipality. Here again the internal wiring work must be of a higher standard than would pass for 110 volt work, and some of the accessories have to be radically different, types known as 'high voltage' fittings having arisen to supply the want. Again, there is a wide difference between what is permissible in 220 volt work and on high tension circuits of 1,000 or 2,000 volts.

Conductors.—We will start with the conductors (wires and cables) for which, inside houses, no material other than copper is ever used. At the present day enormous quantities of this metal are required for electrical purposes all over the world, so there is no great difficulty in obtaining it pure, and this is a vitally important point, for small traces of impurities are sufficient to increase the specific resistance out of all proportion, in which case all calculations based on the use of pure copper would be vitiated. Until comparatively recently chemically pure copper was scarcely obtainable out of the laboratory, and even Mathieson's standard, which is generally quoted in specifications, is not for perfectly pure metal. Not long ago the conductivity asked for was 98 per cent of Mathieson's standard, but now 100 per cent. is more usual. For insulated conductors circular copper wire is generally used, though other forms are being introduced in some cases. There are several different scales of gauge, but the one we shall keep to is the British legal standard wire gauge, referred to as S. W. G., and I give in Appendix I a handy list of useful figures with regard to it. Wires are used either singly or stranded, and preferably the latter except for very small sizes. In a stranded cable it is usual to make all the strands of one gauge, and there are then certain definite numbers of wires that will group together compactly. Three strands will evidently do so, but this number is only used with 2 or 3 small sizes of wires. The next group we can get is that formed by a centre wire surrounded by a complete circle of others. If you try it with the compasses you will find 6 will just go, giving us a 7-strand cable.

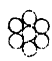


Fig. 20.

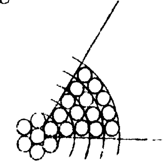


Fig. 21.

(Fig. 20). Beyond this it is easy to determine graphically the natural combinations that will strand round a centre wire since it is a simple series; for if we take the cross-section of a 7-strand cable and divide it up by converging radial lines between each pair, (Fig. 21) we then see that the series is—

$1 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots = 1$
$1 + 6 \quad \ldots \quad \ldots \quad \ldots \quad \ldots = 7$
$1 + 6 + (6 \times 2) \quad \ldots \quad \ldots \quad \ldots = 19$
$1 + 6 + (6 \times 2) + (6 \times 3) \quad \ldots \quad \ldots = 37$
$1 + 6 + (6 \times 2) + (6 \times 3) + (6 \times 4) \quad \ldots = 61$
$1 + 6 + (6 \times 2) + (6 \times 3) + (6 \times 4) + (6 \times 5) = 91$

The numbers can be expressed more simply by the formula:—

$3N \; (N + 1) + 1 =$ Number, N being any whole number.

Whether a single wire or a strand is used, the cross-sectional area of the copper should in no case be less than that of one No. 20 S.W.G. wire and generally of a No. 18, however small a current is to be carried. A smaller wire has not sufficient mechanical strength, and is very apt to get broken or reduced in section in handling. Should the conditions require a larger cross-section than one No. 16, then a strand should always be used, partly because the breakage of one strand still leaves a fair path for the current and also because of its greater flexibility and adaptability.

Copper wires intended to be covered or insulated are usually coated with a film of tin, partly because that metal is less affected by damp and vulcanising compounds, and also because it makes the soldering together of two wires so much easier. The electrical effect of the tin is inappreciable. Bare wire is used for conductors out of doors in many places, but for use in houses the wires must be well insulated, and this can be done in several ways. For such circuits as electric bells and house telephones the wire is covered with 2 spiral layers of cotton wound in different directions, but this was soon found inadmissible for electric light circuits. India-rubber was presently seen to be the best material for the purpose, and was wound on in spiral layers over a preliminary layer of cotton and then protected by cotton tape or flax braiding. This was a great improvement, and indeed in perfectly dry places lasted many years, but it offered a path for leakage in damp places through the laps in the rubber. Practically all wires for this purpose are now insulated with vulcanised India-rubber; in this process the conductor is covered first with a lap of pure India-rubber, then a lap of a specially prepared vulcanising India-rubber, then India-rubber-coated tape. The cable is then kept for $\frac{1}{2}$ to $\frac{3}{4}$ hour at a temperature sufficient to soften the rubber and cause it to become homogeneous—about 300° Fahr. After this the insulation is usually protected mechanically by flax or braid, which is coated with a tarry product to keep the damp out. Such a cable can be put bodily into water and retain its insulating properties; indeed, every coil is usually guaranteed to have been tested after immersion for 24 hours.

This brings me to the question of how the insulating qualities of the dielectric on a wire or of any other insulator are defined. I have explained to you previously that the term 'insulator' is only a comparative one, and therefore it is only a question of figures to express

its resistance in ohms. It is more convenient, however, to take a larger unit, and the resistance is therefore expressed usually in megohms, the term meaning 10^6 (1 million) ohms. A cable of the highest quality for high-tension work will have an 'insulation resistance' of from 2,500—5,000 Ω (megohms) for one mile length. Obviously 2 miles would have half this resistance, and a half mile double it. For ordinary electric light work in houses cable of from 600—750 Ω quality is used, and in dry countries—amongst which Bengal cannot be reckoned—300 Ω is sufficient.

Dry air is one of the best insulators known, and advantage has been taken of this fact in recent years to make cables for various purposes in which air insulation plays a part. The wires are actually enclosed by paper, but this is put on loosely and in such a way as to allow the air to assist in maintaining the resistance. But since damp paper would rapidly become a source of danger, the whole is contained in a tube of lead hermetically sealed. Rubber cables are also often covered with lead—which is forced on by hydraulic pressure—and in some cases there is an armouring of iron or steel wires outside to give mechanical protection and strength.

In certain cases and for certain work it is convenient to have two or even three separately insulated conductors made up into a single cable. In such cases it is usual to put one stranded conductor of circular section central, and then place the other one or two around it concentrically, each as a circle of separate wires separated by insulation from the other conductors within and without. Or the middle and outer conductors may be in the form of a number of small segments of almost rectangular cross-section, which together make up a circular tube enveloping the central conductor. Another form in which conductors are made up for electrical work is that known as the flexible cord. For any movable fitting, or for use with a pendant where appearances must be considered, these special conductors are used, made up of a great number of strands of very small wire, say No. 38 or 40 S.W.G. These are laid together and insulated with pure or vulcanised India-rubber and then covered with braided cotton or silk. From their construction such conductors as these are capable of being bent round angles or even tied in knots to almost any extent without sustaining damage. Two such conductors twisted together spirally constitute twin flexible, and this is the form in which it is most generally used. On a larger scale you will find that the brush leads of dynamos arde mae of heavy flexible conductors, though this will not have a fancy covering of silk but be rather made for standing hard wear, just as the twin flexible in use in mills, &c., is that known as 'workshop flexible' and has both conductors enclosed by strong braiding for mechanical protection.

Joints in conductors of all sorts are things to be avoided as far as pos ible, and it is often possible to avoid them altogether, as I shall show you presently, but, as a general rule, a certain number will find their way into any given installation. It is of the utmost importance that these joints should be mechanically and electrically perfect, though this condition is very apt to be overlooked. It is evidently useless to have—for example—a No. $\frac{3}{16}$. cable insulated

with vulcanised rubber to 750 Ω per mile, with a joint in it where two of the three wires have been cut off and the third merely twisted on to the next length and then the whole covered with a few careless wrappings of pure rubber. That is one example out of many of what one finds occasionally. The properties of a perfect joint are that its conductivity must be at least as great as that of any part of the solid conductor; that it must be mechanically strong and yet not dependant on that strength for its conductivity through mere contact, and that its insulation resistance must be as good as that of the original cable. First, taking the joint in the conductor itself the procedure will be as follows:—

The protective tape is removed for a few inches from both the free ends, and the rubber is then cut away for a rather smaller distance and carefully tapered off; or if the joint is a tee then a clear space is prepared on the unbroken conductor and the insulation on either side is treated in this way. Here is the first danger, namely, that in cutting away the tape and rubber you may accidentally bring the knife down on to the copper; the result may be a very small nick only, but when the wire has been bent about a few times it will open out and render the joint a source of danger. In cutting away insulation remember always to hold the blade of your knife parallel with the wire and to make the cut longitudinally. The insulation then peels off easily, and even if the copper is scratched its sectional area and strength are not materially reduced. Of course in tapering the end of the rubber you have to hold the knife at right angles, but you can then see the copper and avoid damaging it. We now have several inches of bared wire on each conductor and the insulation properly prepared, and the next thing is to clean the conductors. If they are tinned copper—as they almost always are now—they will generally need wiping only, but if they are dirty or untinned a clean-up with fine emery cloth is necessary.

From this point the procedure differs according to the species of joint and the number of strands in the conductor, and we will start with jointing only, considering the re-insulating later on. First, taking the case of a single strand conductor to be teed on to another similar conductor or on to a stranded one, it is simply wound on fairly tightly for about half-a-dozen turns. The soldering is then done at the last two or three turns, and not at the point where the joint actually branches off, thus preventing any risk of breakage due to the hardening of the wire and the unyielding nature of the soldered part. (Fig. 22.)

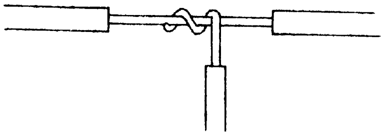


Fig. 22

If a stranded cable is to be teed on to another the bared part is opened up and each strand separately straightened and cleaned, the strands being divided into two groups and saddled over the bared portion of the unbroken wire. Then the groups of wires are

wound around in opposite directions for several turns and soldered as before near the ends (Fig. 23).

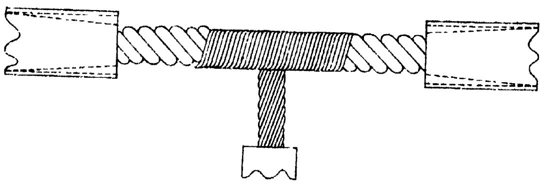


Fig 23.

In making a joint between the free ends of two small single wires the best way is to place them side by side for an inch or two, bind them together with thin tinned copper-wire ('binding wire' No. 22 S.W.G. or thereabouts) and solder (Fig. 24). Or they can be

Fig 24.

twisted, each spirally round the other, and soldered, but this does not make such a neat job (Fig. 25).

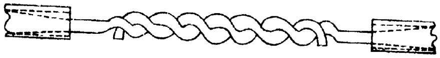


Fig 25.

Where two stranded conductors are to be joined at their free ends there are two recognised methods of doing it. The first is the scarfed joint, which is also used for fairly large solid conductors in many cases, as for instance the main coils of dynamo magnets. The strands are soldered together solid, and then each conductor is filed to a taper on one side until a large flat surface is available; the two tapered surfaces are then brought together, and the whole bound with binding wire and soldered. This joint is fairly self-testing, since its mechanical strength is almost solely dependent on good soldering (Fig. 26).

Fig. 26.

The next best method is to interlace the separate wires. If two stranded conductors are to be joined, each is untwisted for about half the bared up length, and the wires so opened up are straightened out until radial. The core or central group of wires—if the cable has above three strands—are cut clean across at the middle point, and then

the two conductors are brought together until the cut cores butt against one another. Then the outside wires of each cable are alternately

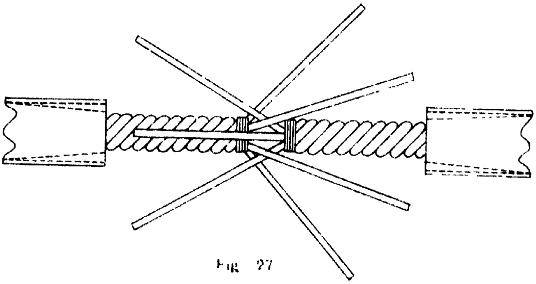


Fig. 27

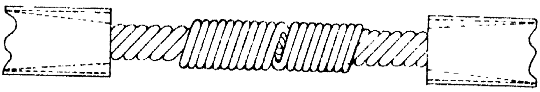


Fig. 28.

passed between those of the other and wound around the conductor beyond in reverse directions (Figs. 27, 28). This joint, even when unsoldered, has great mechanical strength, and when soldered fairly through is also thoroughly reliable electrically.

In all cases it is essential to use rosin only as a flux when soldering, since acids and fluids almost always cause corrosion sooner or later, with the consequent reduction in cross-section. We must now consider the insulating of the joints made in any of these ways. If the cables are of a good quality and vulcanised, it is evidently best to also vulcanise the joints. The process of doing this has been already described, and in carrying it out in practice the prepared joint is placed in a special iron box and heated either by pouring in a melted mixture of sulphur, &c., or else electrically by means of internal heating coils and a portable battery. The one thing absolutely essential in making a good vulcanised joint is cleanliness. The whole of the material used, and the hands of the operator, must be kept clean with benzol, or the result will be bad. Unfortunately to vulcanize a joint takes time and trouble and needs good supervision, the consequence being that scarcely any firm will take the trouble to do it, despite the obvious advantages. In fact to specify that all joints are to be vulcanized is, I have found, equivalent to entirely forbidding the use of any joints at all.

Failing this, the ordinary method of insulating a joint is with pure India-rubber tape. I have already told you that the vulcanised India-rubber of the cable should always be tapered down towards the joint; a little 'rubber solution'—*i.e.*, India-rubber dissolved in carbon-bisulphide—is spread over the surfaces and the tape is then wound on spirally, each turn overlapping the one before for half its breadth. Thus three complete layers will give six thicknesses of the tape. Over this is wound a layer of India-rubber coated tape in the same way, fixed with the solution and preferably tarred afterwards. A joint carefully insulated in this way is quite reliable for some years, at any rate for indoor work.

Lamps.—Let us now consider incandescent lamps for a few minutes. Until a few years ago one firm—The Edison-Swan Company—had the entire monopoly of the lamp trade owing to their master patents; at present there are scores of makers of good lamps, though I still consider the 'Ediswan' lamp holds its own as one of the most reliable. Amongst other good ones may be mentioned 'Robertson,' 'Sunbeam' and 'Stearn' lamps.

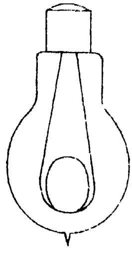
There are many types adapted to the different needs of the generating plant and the consumer, but for any given purpose a lamp should have the following characteristics:—

(1) It should be economical in current for the light given, *i.e.*, the power used in it in watts divided by the candle-power should give a comparatively low quotient.

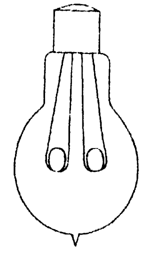
(2) It should have a long life before blackening or burning out.

Now these two properties militate somewhat against one another; the more economical the lamp is in current, the higher is the temperature of the filament raised and the whiter is the light, but the fact of employing a higher temperature is courting the destruction and disintegration of the filament. In order to hit the happy medium you must consider what the cost of current is. If you are paying a very high price for current it will be best to put 'high efficiency' lamps in, since they save a lot of current and are not expensive to replace; on the other hand, where current is very cheap it pays to use more current and save lamps.

The ordinary pressures met with are 110 and 220 volts, and the lamps for these pressures have to differ somewhat. Ohm's law holds



110 Volt Lamp.
Fig. 29.



220 Volt Lamp.
Fig. 30.

good in the lamp as elsewhere, and with a given pressure the current depends on the resistance of the filament. So for a given thickness of filament at a certain temperature double the length must be employed for 220 volts, in order to give the current that 110 volts would produce in a single length. But note here that the resistance of a lamp filament taken cold is not much guide to its resistance when hot. Unlike all the metals, the resistance of carbon—of which of course the filament is made—drops as the temperature rises, and at the very high and (in different lamps) variable temperatures of working is altogether a different figure to that obtained with a cold lamp.

When a lamp has been at work a few hundred hours the globe begins to blacken from deposition of carbon on it. It is really a case of molecular bombardment *in vacuo*, the particles being shot off from the negative side in all directions in straight lines, and occasionally a very black lamp will be found in which there is a clear line where the positive side of the filament has entirely shielded the glass from bombardment, showing that the particles take a perfectly straight course. As lamps get black their useful candle-power diminishes and their efficiency consequently falls, so that it does not pay to use them to the bitter end, and where placed among inflammable materials they are even somewhat apt to be a source of danger, since the bulbs become hot through arrested radiation. Often, however, the lamp settles the question by 'burning out,' *i.e.*, the filament gradually gets thinner from loss of carbon and the weakest spots rise in temperature above the rest until finally a break occurs.

Different candle-powers are obtained in lamps by giving them varying lengths and thicknesses of filament, *i.e.*, different areas from which light will be emitted. The most generally useful lamps are of 8, 16 and 32 candle-power, the latter being almost too strong for comfort for indoor use. Lamps of 4 or 5 candle-power are sometimes used for passages and small rooms, and also as artificial candle lights; but at

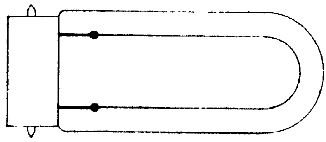


Fig. 31.

present these cannot be obtained for use with a higher pressure than 110 volts owing to the difficulty of making suitable filaments. They are fitted with small B.C. terminals usually, so as to fit into a miniature bayonet-holder. Lamps of miniature size and very low candle-power can be obtained for special purposes, but only for use with low pressures of 2 up to 20 or 30 volts, such as are available with portable batteries; these we need not consider at all. Lamps of 50 C.P., 100 C.P. and up to 2,000 C.P. are made for all ordinary pressures, and are sometimes useful for lighting large outdoor spaces or buildings, but they consume far more power for a given candle-power than an arc lamp and are therefore to be avoided where the latter can be used unobjectionably.

The most recent development in incandescent lamps is the Nernst lamp, the principle of which differs considerably from that of the Swan lamps. Instead of a filament of pure carbon some of the rarer earths, such as are used in the Welsbach gas lamps, are employed. These conduct only when heated, so a preliminary heating is necessary by means of a spirit lamp or a platinum coil in the circuit. As these earths are oxides there is no necessity to keep them *in vacuo*, and as they can be heated to intense whiteness without disintegration, great economy should be obtainable. The lamps are not yet obtainable commercially.

So far I have been considering lamps for parallel burning, but in some cases special lamps are made for series work. In this case, as already explained, the current passes successively through every lamp, while

each lamp causes a certain number of volts to be lost. As the heat given off depends on the watts expended, so does the light under given condition of temperature in the filament, and a 64-watt 16-C.-P. lamp may be either made for 110 volts and ·58 ampère for parallel working, or for 2 ampères at 32 volts in series with any number of others on a high pressure circuit. In series working if one lamp gives out for any reason the circuit is broken, and all the rest are therefore put out; this has to be guarded against by automatic gear which completes the circuit afresh and puts in resistance equivalent to that of the burnt-out lamp. Series working of incandescent lamps is consequently not often employed for domestic work, and seldom even for public lighting. The holders of series lamps contain the automatic devices, which consist of a spring contact-maker to complete the circuit when the lamp is not in the holder, and of another wherein the contact is only completed if the lamp burns out by a spark traversing a small short circuiting device with its terminals separated by an easily pierced sheet of insulating material. In Government House, Calcutta, the ball-room is necessarily lit by lamps run two in series; for the lighting is by artificial candle lamps, which, as I mentioned, are not obtainable for a pressure greater than 110 volts. As the Supply Company's pressure is 225 volts, this artifice was rendered necessary, but this is not in the same category as ordinary series lighting, and the failure of one lamp affects only one other.

In ordinary incandescent lamps the power consumed varies from $2\frac{1}{2}$ to 4 watts per candle-power, the first figure being for 'high efficiency' and the second for 'long life' lamps; thus a 16-C.-P. lamp will take from 40 to 64 watts. For 220-volt work the lamps are generally made for the lower efficiency, and a 220-volt 16-C.-P. lamp requiring 64 watts will take $\frac{64}{220}$ or ·29 ampère. In making calculations I shall always assume 64-watt lamps, since even if not installed at first they probably will be sooner or later, and this will give a factor of safety in the wires. You will gather that for any given number of lamps the higher the pressure the lower the current, and therefore the smaller the conductors, so 220-volt work saves considerably in prime cost on this account. Against this must be put the fact that good high efficiency lamps are not obtainable for the pressure and that the life of even the ordinary ones is shorter than that of low voltage lamps. The life of a lamp is generally reckoned as 1,000 hours of burning, but it may extend to double as much, and it may end in a few days. The current is conveyed to the filament by platinum wires sealed into the glass and cemented on to the carbon; fortunately this metal has the same coefficient of expansion as glass

Terminals and holders.—On the outside there are various forms of terminals for putting the lamp in the circuit, with lamp-holders adapted for each. The simplest is where the platinum ends are bent into loops, which are gripped by little spring hooks in the holder, but this is not much used now except for high candle-power lamps. In another form one wire is soldered to a central piece of brass and the other to a ring outside it, the two terminals being insulated from one another by plaster of Paris or a vitreous material, which also cements the terminals to the lamp. The ring has a screw thread and fits into a screwed

holder which has a central terminal forced upwards by a spring. This arrangement is known as the 'Edison screw lampholder.'

You will here generally find the lamps have B.C., or brass collar terminals, the leading in wires being soldered to two semi-circular pieces of brass, surrounded by a brass collar and the whole cemented to the globe as before. In this class of lamp, unlike the last described, the

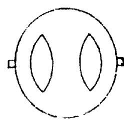


Fig. 32.

outside collar is not part of the electrical circuit, nor is the outside frame work of the lampholder. In the holder there are two spring

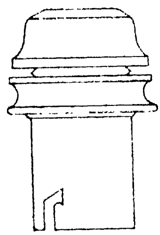


Fig. 33.

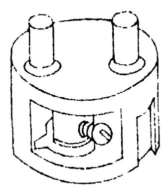


Fig. 34.

contacts which engage with the two brass segments of the lamp cap, and in the latest patterns, for use on high voltage ($220^{v.}$) circuits, each of these contacts is entirely surrounded by porcelain, in which material they are also mounted. This class of fitting is known as the bayonet-holder, since the lamp is fixed in it by a thrust-and-turn motion.

A lampholder may be required either for attaching to a bracket or for hanging down as a pendant; in the former case it will have a $\frac{3}{8}''$ or $\frac{1}{2}''$ emale screw thread; in the latter case a 'cord grip' will be attached to it—this being a device consisting of a split cone of wood, with two grooves somewhat smaller than the wires which grip them and prevent any strain coming on the lamp terminals.

No satisfactory switch lampholder for 220 volt circuits exists at present, and it is best to avoid using the ordinary types on circuits for the higher pressure as there is a possibility of an arc forming inside the holder. The problem of designing a switch to go in such a small space and yet fulfil all the conditions of 220-volt supply is no easy one.

Cut-outs.—Any device for breaking a current automatically when too great or too small may be called a cut-out; but for the present I am confining myself to work in houses, where a cut-out generally means a fitting containing a short length of fusible wire in series with the circuit, which melts and breaks the current when it is excessive. If a conductor is large enough to carry 10 ampères and you put 20 through it, the result is heat; if you further increase the current, the wire will get hot enough to melt its insulation, and finally to fire it and any inflammable material near. Against this danger it is necessary to protect

houses, so cut-outs are introduced at certain points and provided with a "fuse" which will melt before the conductor has arrived at a temperature to damage its insulation. Where they should be placed is a matter I shall go into later on; for the present we will look at their construction only. The essential requirements of a cut-out—and the same may be said of switches, ceiling roses and wall plugs which we shall deal with presently—are that both cover and base should be of incombustible (preferably non-conducting) material, well insulated as to the base, and with sufficient space between the terminals to prevent an arc maintaining itself under any circumstances; and they should have no conducting parts at the back. Nearly all small house cut-outs are now made with a porcelain base and cover; for 110 volt work only two segments of brass, with terminals on each for the conductor and the fuse, are needed (Fig. 35). But for 220 volts new types have been introduced,

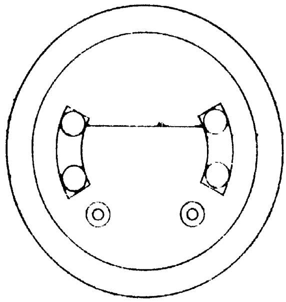


Fig 35.

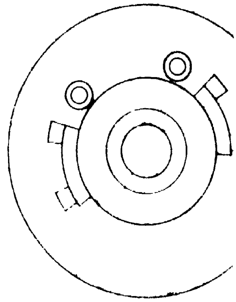


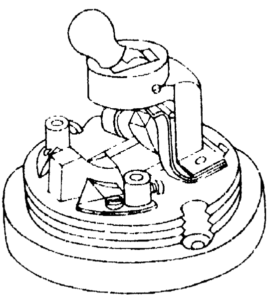
Fig. 36

in the best of which the fuse wire has to pass through holes in a central hollow cylinder of porcelain lined with plaster of Paris (Fig. 36). This chamber reduces the liability of damage when a fuse melts—for the suddenly heated air is liable to blow the cover to pieces; unless it is ventilated as recommended by the Institution of Electrical Engineers. In these cut-outs a single strand of No. 40 copper wire is the safest fuse to use for a circuit of one or two lamps only, but it should be thickened up by one or two more strands near the terminals or it may melt unduly often from deterioration where it touches the plaster. For ordinary work, and for cut-outs contained in distributing boxes, pure tin wire is a better material, since its melting point is far lower than that of copper. Lead is often used, but is very unreliable owing to the coating of oxide which always forms on it, and it should be avoided. Much annoyance is caused in a house when the lights go out owing to the melting of a fuse, and in reality this seldom need occur if the fuse wire is of the right size and carefully fixed in, and if no unnecessary cut-outs are introduced. In Appendix II will be found a useful table of the fusing currents of various sized wires of both tin and copper, which may be used as a basis of calculation.

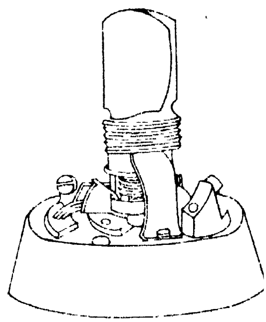
In many cases it is necessary or desirable to have a fuse in each pole of a circuit, and cut-outs used to be made with two sets of terminals for this purpose Such 'double pole cut-outs' should never

be used unless there is a porcelain partition between the two poles, and even then they are undesirable, since the porcelain may get broken and expose the conductors to a chance of short circuits. The modern system is to group all the cut-outs at certain 'distributing points' instead of putting them casually wherever it is convenient, and in such cases all the cut-outs of one polarity for a number of different circuits are placed in a single box. Slate is then generally used as a base, and in some of the best types all the fuses are mounted on vertical porcelain bridges which can be changed at a moment's notice.

Switches.—A switch is a device for making or breaking a circuit whenever it is requisite by completing the metallic connection between two separated terminals on the same pole. The essentials of a good switch, in addition to the points just now mentioned, are:—(1) There should be ample rubbing contact to prevent overheating. (2) There should be a quick break (usually obtained by a spring) of sufficient length to prevent an arc being maintained when the current is broken; the length of break must therefore be regulated according to the pressure of the supply. (3) There should be no possibility of the switch remaining in an intermediate position between on and off. (4) Shocks should not be communicated through the handle which should be well insulated from the conducting parts.



Tumbler switch.
Fig. 37.



Ediswan switch.
Fig. 38.

Most switches are constructed on a lever system, so that a small motion of the handle causes a large motion of the breaking gear, and a spring is generally fixed in such a way that at the moment of breaking contact, it comes into action and carries the lever to its extreme point almost instantaneously (Figs. 37, 38).

Ceiling roses.—When a pendant is to be hung from a ceiling it is necessary to have some support for it, as well as a means of connecting the flexible wire to the ordinary conductors. A good ceiling rose for this purpose should be entirely of porcelain, base and cover. The conductors come in from the back and pass through holes in the porcelain to brass connecting screws. From other screws on the same plates the flexible wires are taken off to the lampholder through a hole in the cover. If any strain were put on the flexible, in such a case, it is more than probable it would break at the terminals. To prevent this

some ceiling roses are fitted with a cord grip, somewhat as described in the case of lampholders. The more ordinary method is to pass the flexible through the cover of the ceiling rose and then tie a knot in it, leaving a small amount of slack in the cover.

It used to be the custom to put fuses in ceiling roses, allowing an extra terminal for the purpose, and in some cases this may be necessary.

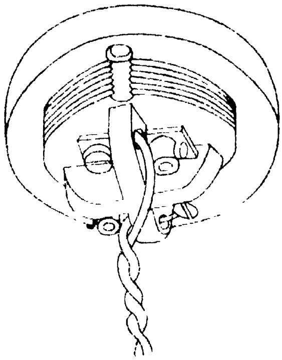


Fig. 39

As a general rule, however, it is far better to avoid the practice by putting all necessary fuses in places where they are accessible. In using a 3-terminal ceiling rose without a fuse, the fuse terminals should be bridged over with a piece of copper wire of as large section as the conductor. For 220 volt work the terminals of different polarity should be separated by a porcelain partition.

Wall sockets.—For many purposes portable lamps are used and the flexible wires leading to the fitting must then be capable of easy disconnection from the circuit. In such cases a wall socket is used, and a plug is attached to the flexible wire of the fitting. Wall sockets and plugs, like the other fittings just described, are usually made of porcelain, and the wires are brought through holes in the back to the terminals. Two general forms exist—"2-pin" (Fig. 40) and "concentric" wall sockets.

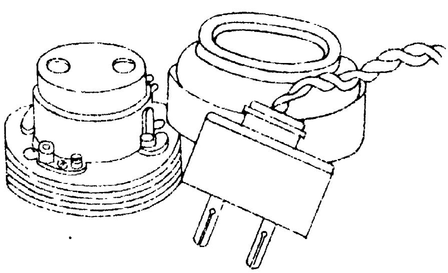


Fig. 40.

In the former type the plug has two projecting brass pins, split to make them springy, which will push into two brass tubes in the socket;

the conducting wires are joined to the tubes and the flexible is taken off from the pins. The tubes should be sunk sufficiently in the porcelain to prevent an accidental short circuit occurring.

In the concentric type the conductors are led to a central pin and a concentric ring respectively, the plug having a central tube to fit the pin and an external band to fit inside the ring. In this type the liability to short-circuit is greater and they are not so satisfactory, especially for 220v. work. In each case provision is generally made for a fuse, but it is sometimes better not to use one. The plug should have either a cord grip or else provision for a knot to be tied in the flexible inside it, otherwise there will be frequent breakage, but unfortunately the plugs in the market generally have no such provision. Users take some time to learn that the flexible is intended to carry the current and *not* to pull the plug out by. It is only after paying a good many fees for repairs that this is realised.

Running circuits.—As a preliminary to considering the best practical systems of arranging wires and fittings for given purposes—which I propose to deal with in the next lecture—we will now turn to the actual methods of fixing the wires in any part of a house. When electric lighting started the only experience to go on was that of electric bells, and consequently the conductors were simply stapled to the walls or woodwork. The staples generally damaged the insulation—poor enough to start with—and breakdowns were consequently frequent, and yet I quite recently found some newly erected work of this description in an installation. The first improvement on this was the use of wooden cleats with two grooves some distance apart for the wires, which were attached to the wall by a central nail. Such work was very ugly, and the fact of having the wires on the wall conduced to leakage. Later a strip of wood was first fixed on the wall, and the wires were cleated to this; now this was a very great improvement, since both dry wood and air are excellent insulators, but the rough appearance of the work and the liability of the exposed wires to damage caused it to be generally abandoned. For temporary work, however, it is probably about the cheapest and best system. A modification of it, which is still extensively used in the United States, is even better electrically and not nearly so unsightly. In this system double cleats of porcelain are used, one set of which are fastened to the walls at intervals to keep the wires spaced away from it, while the second set are screwed on above and hold the wires in place. Where this system is adopted—and I consider it has many points to recommend it here—the two wires should be kept always at least 2 inches apart, and more for main conductors or high pressures.

Another somewhat similar system is the use of porcelain insulators, and the remarks about spacing generally apply to this system also. But for temporary work, liable to be dismantled at any time and under proper control, there is no harm in running two high-class vulcanised wires on one line of insulators, since the insulation on the wires themselves will keep them safe for a considerable time even when exposed to this climate.

Generally speaking nearly all wires in houses are at present placed in wood casing—a system naturally evolved from that of cleating.

Here the wooden backing has two grooves in it for the wires, with a fillet in between, and capping is fixed continuously over it so that the wires are entirely enclosed. As a rule no wood but teak is admissible here in India, since the omniverous white-ant soon devours all others. The proportions of a well-designed casing are shown in Figure 41,

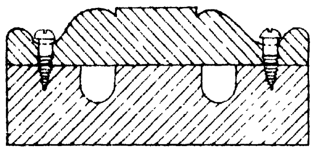


Fig. 41.

the actual size being of course regulated by that of the wires For carrying two single small wires, say two No. 18 S.W.G., the grooves must be about $\frac{3}{16}$ in. wide and deep. The central fillet should be never less than $\frac{1}{2}$ in. wide and the thickness of the casing should leave $\frac{1}{2}$ in. of wood under the wires. Outside the grooves there should be sufficient width to take the fixing screws without any risk of their penetrating the wires except through gross carelessness. The capping need only be quite thin, say $\frac{3}{16}$ in., and is generally neatly moulded for appearance sake. It is a very general practice to fix the capping on by screws to the central fillet of the casing; this is ordinarily harmless enough, but it is far better, especially for 220 volt work, to use the outside. Where trouble occurs in casing, it generally originates with a carelessly fixed central screw, which penetrates one wire and partially bridges the fillet across to the other. A good firm will generally use brass screws where it is specially damp as iron ones are liable to rust up. I always specify that casing and capping shall be varnished inside and out before erection, as this is a great protection from damp; either copal varnish or shellac is suitable, but in either case it should dry thoroughly before erection. If the work is to be painted afterwards it is advisable

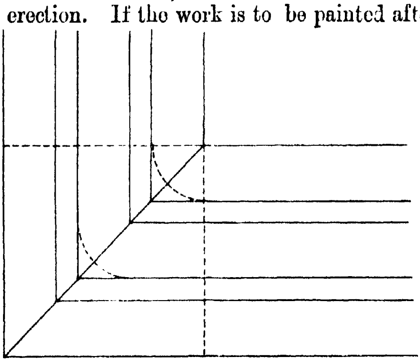


Fig. 42.

to leave the outside unvarnished and to give it a preliminary coat of paint instead. Cracks and openings behind the casing or between casing and capping should be carefully puttied before painting, or the work will look rough.

When the wires are being put into the casing, much damage is at times done from injudiciously hammering them. If ordinary pressure from a piece of wood is not sufficient the grooves are too small, and the casing should not be accepted. Damage also frequently occurs where the casing takes a sharp turn, for the angles of the wood pierce the insulation and give access to moisture; all sharp projecting pieces should therefore be rounded off as shown in Figure 42.

Successive lengths of casing should not simply be butted against one another. It is best to cut away the fillet and side pieces of one length and the base of the succeeding one, and thus to make them overlap. Furthermore, the lengths of capping should always break joint with the casing

It often happens that one set of wires have to cross over another set in which case a bridge of casing should be carried over. If a branch circuit is taken off by joints the outer wire will have to cross over the inner one of opposite polarity, and here again a bridge of casing should be used. On no account should wires of opposite polarity lie in the same groove or touch one another in crossing, otherwise the whole idea of a separating fillet is rendered futile.

Pattrasses.—Switches, cut-outs and other fixtures are always mounted on wooden blocks, partly to further insulate them from damp walls and partly to raise them above the level of the casing for appearance sake. The blocks should have a groove cut behind them, so that they fit neatly over the casing, which should not terminate outside the block; in fact casing should invariably be so run that there are no places where the wire is exposed in any way.

Accessibility of casing.—On the other hand the casing itself should, as far as possible, be easily accessible. It is the gravest mistake to run it in such a way that the floor or ceiling has to be pulled to pieces in order to trace a fault in the wires. It sometimes happens that a room will be seriously disfigured by even the most handsome casing, though if neatly moulded and well painted it is generally quite unobjectionable; in such cases there is no option but to run it hidden away. But in order to facilitate inspection, should it prove necessary, the floor boards above the wires should be butted and fixed with brass screws, in order to avoid the extra work and expense of opening up tongued and grooved boards, or extracting rusted iron screws. In order to effect partial concealment some engineers sink the casing in the plaster flush with the wall. This enables the moisture of the fresh plaster to play havoc with the wires, exposes them to the risk of having picture nails hammered into them, and is a practice to be in every way discouraged. Where wires must pass through walls or under plaster the best way is to run both together in a porcelain, or failing that a compo, pipe which should be sufficiently large for the wires to be easily drawn through it after the wall has been made good. Where necessary a wooden box with an inspection lid can be made to cover the junction. If wires have to be run across a floor of concrete, cut a groove to hold a considerably larger size of casing than is required for the wires, and fill in the space round each wire with Stockholm tar or bitumen, or, as an alternative, run them in a pipe of ample size. The making good of the concrete will then do no harm.

Recently there has been an outcry in England for a better system of running wires than that of wood casing, and much discussion has arisen as to what can take its place. While I believe that the majority of us are still in favour of carefully executed work in wood casing, there is a powerful minority advocating a variety of other systems. I will enumerate the chief of these, and comment on them briefly.

Lead-covered cable.—Not infrequently lead-covered cables are buried direct in walls and plaster; in India, however, it is inadvisable to do this, as the lead is attacked by certain salts in the plaster and speedily destroyed, especially if a slight leak develops and allows electrolysis to take place. The result is that the cables inside become exposed and soon perish. An installation on this system in Calcutta is now likely to need re-wiring almost entirely from this cause, after only a few years' working.

Other engineers recommend twin lead-covered cable fastened direct on walls. I do not think the system is good electrically for India, and in houses its appearance would certainly condemn it off-hand.

Gas-pipe system.—On the other hand, what are known as tube systems have a great deal to recommend them. Originally some one tried running a service of ordinary compo gas-pipes in the walls in the usual way, but arranged with electric light wires inside. The great disadvantage of this is the liability to damage through nails, though that liability exists, and is perhaps more dangerous, with gas. The use of iron pipe in place of compo is a great advance, but wire is apt to be damaged in drawing the pipe over it This was later on obviated to some extent by running all the pipes in the walls first of all, keeping them as straight as possible, and then drawing the wires through by a pilot string afterwards. This greatly reduces the amount of handling the wire receives and therefore the labour, but the insulation is apt to be stripped by inequalities and burrs in the pipe, especially where a piece has been carelessly cut. It is difficult to draw in very great lengths of wire without unduly straining it, and therefore traps were introduced at intervals to act as drawing-in points. There are many advocates for this method of wiring, but of late two new and rival systems have been developed which are a further advance on it.

Simplex conduit.—The first of these is known as the Simplex conduit system. In this the pipes used are thickly enamelled inside and out with a material that gives a beautifully smooth surface. In order to ensure the absence of burrs the pipes are not solid drawn, but simply lapped over, the enamel on the outside apparently closing the break. The lengths of pipe are made so that one end tapers just enough for it to fit into the next, and therefore the running of such a system of pipes is simplicity itself. Special junction boxes, fittings for tee-joints and so forth, are made in the same material. The advantages of this system are fairly low prime cost—a very important factor when house-wiring is so expensive as at present—fair security for the wires against damage from nails, and ease and safety in drawing them in. The chief disadvantage appears to me to be the fact that the tube is not waterproof either along its length or at the joints. Consequently it may be to

some extent compared to lead-covered cable when the lead has perished, if it were not for the fact that new wires can easily be drawn in at any time when necessary.

Insulated conduit.—In the second new system iron or steel pipes are coated internally with a thick lining of an insulating composition. The material is, I believe, a patent, but it looks somewhat like a very hard variant of bitumen. It gives a smooth internal surface which would not hurt the insulation, and is claimed to be a high quality insulator itself, so that cheaper insulation may be used on the wires themselves. The pipes in this system are screwed together in the usual way and make a perfectly water-tight system, while the internal surface is not liable to sweat. Altogether the system seems an excellent one, but it has the grave disadvantage of high prime cost.

I have samples of the two species of tubes here, but they have come into use so recently that I cannot claim any practical experience with either. Each appears to have certain fields for useful rivalry with wood-casing and both are being very extensively used in England.

LECTURE III.

House wiring.

TO-DAY I shall deal with different fixtures for carrying incandescent lamps, their arrangement and the manner of wiring them, with the different methods of designing the scheme of wiring an installation, and with the practical methods of erecting and testing the same.

Illumination.—The area which a single 16-C.-P. lamp will effectively light is generally taken as about 100 square feet when it is placed 7 feet above the floor. Naturally a great deal depends on the colour of the walls and ceiling of the room and on the strength of illumination desirable; a room with a number of people spread over it, doing work requiring a strong light at every point, would need more lamps than the above approximation, whereas for a bedroom considerably less is sufficient. And in most cases it is not necessary to light every corner of a room strongly, especially when one remembers that most people are accustomed to arrange their positions to suit the existing lights. But the greater flexibility of electric lighting is getting rid of this habit, and a far better general illumination is now expected than is obtainable from average oil lighting. Then, again, a great deal depends on the way in which the lamp is shaded. Where light and not appearance is the first consideration, a plain conical shade of opal glass or enamelled iron throws the light down and around best of all. Most ornamental shades absorb a large percentage of the light, especially when they fit completely over the lamp, and silk shades are in this respect the worst offenders, though they give the most pleasing lighting effects.

Rooms are sometimes lit by means of rows of hidden lamps which throw their light on to the ceiling from whence it is distributed; this method of lighting is naturally wasteful of power, but it gives a diffused effect entirely without shadows, and is about the best substitute for daylight.

Fittings.—Fittings for carrying electric lamps may in general be divided into three classes—brackets or wall fixtures, pendants or ceiling fixtures, and portable fittings. Brass and wrought-iron are the metals generally employed in the manufacture, the former being lacquered bronzed, or plated with silver or gold, and ornamented in some cases with copper-work, the latter usually painted a dead black.

When a circuit is run to serve a bracket, one wire is taken to a convenient point for the switch, generally just underneath the fitting, and here a small loop is left which can later on be cut and connected to the switch terminals, and two ends of sufficient length to run down the bracket are left projecting from the wood block; these wires are then threaded down the tube and fixed in the lamp-holder terminals. One precaution should be observed and is apt to be overlooked: the outside tape or braiding of the insulation should in all cases be removed for an inch or two before the wires are connected up. This tape is merely a mechanical protection, and is liable to cause leakage if left in contact with the parts carrying current. Often brackets for two or three lamps are used, and the usual practice in this case is to run a pair

of wires down each arm and then joint them on to the conductors at the base of the bracket. This means four or six separate joints, in a position where it is by no means easy to vulcanise them, and each a source of weakness to some extent, especially in a hot damp climate. Where manufacturers realize this and make the tubes and terminals a trifle larger, there is no necessity for any joint at all. I give you a diagram of the wiring of a 3-light bracket as it should be done, *i.e.*, by what is called the 'looping back' method. The conductors are

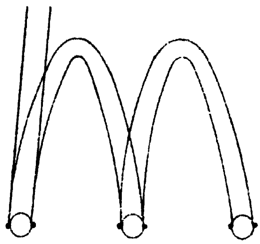


Fig. 43.

carried up to one lamp-holder, and from the same terminals two other conductors are carried back down the tube to the base and then on to the next lamp-holder, and so forth. The advantages of this method are obvious, but as a rule, unfortunately, only two wires will go into the tubes and only one strand into the lamp-holder terminals. I am assuming the use of No. 18 S.W.G. wire, which is the smallest generally allowed, and which is almost always used for lamp leads.

Turning now to pendant fittings, the simplest is known always as the "plain pendant." From a ceiling rose hangs a length of twin flexible cord to the cord grip of a pendant lamp-holder, and the lamp and shade complete the fitting. The switch will be elsewhere, on a convenient wall, and generally near the door by which the user enters for choice. Here there are no complications, for the ceiling rose obviates any joint between the flexible and the encased conductors. Sometimes in place of a single lamp-holder there is a 3-light arrangement, generally a hollow ball with three lamp-holders projecting from it. Here 'looping back' can generally be resorted to so as to avoid joints. Metal fixtures to hang from ceilings are known as ceiling lights or electroliers, according to whether they hang high up or low down. For a few lights only these are generally wired like brackets, but where the number of lights is great the case becomes more complicated. It is then usual for the fittings to be wired completely by the makers, leaving only the connection to the conductors to be made. In many cases it is desirable to have the lamps controlled in two groups by separate switches, in which case alternate lamps or tiers are connected to two separate circuits.

Not infrequently it is necessary to adapt gas- or candle-fixtures for use with electric light, and various devices then have to be resorted to. In the first place, if gas fittings are used all connection with the gas must be entirely cut off and the fitting must be properly insulated at the point of support. If the tubes will then carry the wires all is straight forward, but generally this is not the case. For instance, the candle chandeliers at Government House, Calcutta, are now converted

into electroliers carrying miniature electric lamps in artificial candles. The first thing to be done was to get the wires from the top of the fitting to the bottom; either therefore the old solid rods had to be replaced by hollow ones or else the wires had to be carried externally, the former alternative being finally adopted. But the glass arms leading to the lamps were solid, and to replace them would have been almost equivalent to buying new chandeliers. It was decided consequently to obtain flat twin flexible cord, made up of 2 cords side by side and covered over with silk; this was run along the top of the arms and clipped on by little silver-plated clips, these cords being jointed on to the conductors bringing the current down from the ceiling.

Portable fittings include tall floor standards, table standards and hand-lamps of various sorts. In nearly all cases portable fittings are fed by a flexible cord ending up in a plug which can be fitted into a wall socket wherever it is required. Sometimes there is a switch on the fitting to save the trouble of opening up the plug, but such switches are generally of inferior construction and should be avoided. Occasionally instead of a wall plug there is an 'adapter' on the end of the flexible cord, constructed like a lamp end and such that it can be pushed into any conveniently empty lamp-holder when a light is required.

Main house-board.—Let us now turn to an installation of lamps in a house and see how it *can* be carried out and how it *should* be. We will take it for granted that the supply is to be delivered to the house either from a public supply company or from a private plant, and will start from where the wires entered the premises. The wires may be brought in either underground or overhead. If the latter is the case a lightning arrester should always be fixed to protect the house, and types of these pieces of apparatus will be described later on.* Arriving indoors, each wire goes to a main cut-out of suitable size for the maximum current. If this is above about twenty ampères, a strip of sheet tin will be generally employed for the fuse in place of wire. A main switch should also be fixed in each pole; this may appear unnecessary, since one such switch puts out every light, but it must not be overlooked that so long as one pole remains connected it is possible for leakage and its attendant troubles to occur. Main switches for fairly large currents are generally connected by a link of vulcanite, so that they switch on and off simultaneously, and the main switches and fuses are usually mounted on a slate or marble base contained in a lock-up box. A dry locality should of course be chosen for the main controlling apparatus. Near the main switchboard will be fixed the meter which determines the number of units used—at least if the supply is from a public company—and I shall devote a little time to meters and their testing presently. It will suffice here to say that it is customary when doing the wiring to leave a loop of about four feet of wire on one pole, in a convenient place where the meter can later on be erected and connected up. Occasionally a voltmeter also is fixed near the main switch-board to check the pressure of the supply, especially in large installations. This will of course be connected across the poles, and not in the same way as the meter. From the switch-board there are two distinct systems of arranging the wires so as to serve lights

* Lectures V and VI.

where they are wanted, the 'Tree' and 'Distribution' systems, besides combinations of the two.

Tree system of wiring.—The tree system was the one naturally evolved when first the incandescent lamp came into use and made parallel burning a possibility. It is now seldom employed, and is dying a natural death, so I will only devote a moment to it. On this system two conductors, large enough to carry all the current of (say) one floor of a house, are taken from the main switch-board through the nearest rooms in turn, and wherever a lamp is required a double Tee joint is tapped off. Or, again, a smaller pair of sub-mains may be tapped off to serve some side rooms, and the lamp circuits will be tapped off these. Evidently, after passing through a few rooms, the current to be carried by the main beyond will be considerably less; the main wires are then cut, and two more of suitably smaller section are joined on to them, these in turn being carried on further in the same way. Several similar reductions of section are sometimes made. The system is clumsy and full of joints, and the cut-outs have to be put in all manner of impossible places, so it is very seldom advisable to use it, though it is safe provided proper precautions are taken. Thus, wherever the cross-section of the main wires is reduced, and wherever a branch of smaller section than the main is tapped off, there should be cut-outs on both poles, and the fuses in these should be calculated to protect the wires up to the next fuse or to the end of the circuit if there is no other. The fuses at a Tee joint, where a lamp or lamps are to be run, should be small enough to protect the flexible wires (if any) unless there are further tappings for other lamps beyond which have their own fuses. In the final lamp circuits it was generally the custom to put a fuse on one pole only of the lamp lead, and to fuse the other pole in the ceiling rose or wall plug, but it is generally preferable to bridge the fuse terminals of these fittings with a piece of thick copper wire and fuse the circuit properly at its junction. You will notice that I have so far said nothing as to the size of wire to be used for given conditions. I have not done this for the tree system, as I do not suppose you will ever use it, but when you know how to make calculations for the distribution system you will have no difficulty in doing the same for this, should occasion arise.

Distribution system.—The modern system of house wiring is to work from distributing centres, and not from the main switch-board.

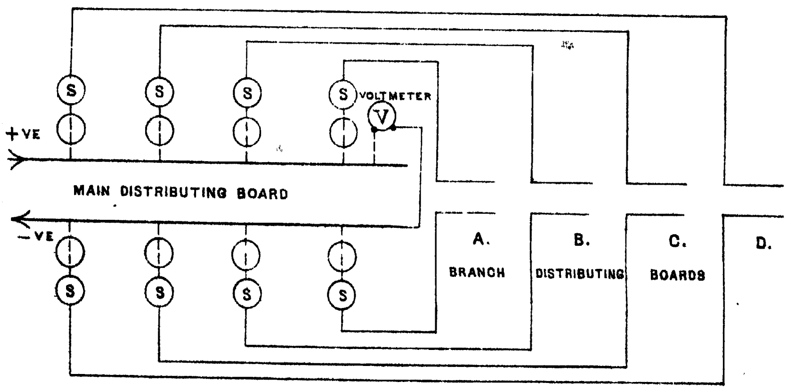


Fig. 44.

One or more positions are chosen centrally in each floor or block of the building (according to its size and shape) around which rooms are grouped fairly uniformly. Let us assume a case where it is convenient to have four such distributing points, A, B, C, D, as follows:—

Branch distributing point.	Distance from main board.	Number of 16-c.p. 110v. lamps.	Current at 4 watts a candle.
	Feet.		
A	60	30	17·4
B	100	15	8·7
C	180	20	11·6
D	250	40	23 2
Total ..	...	105	60·9

Let us further assume that the lamps consume 4 watts per candle-power (*i.e.*, 64 watts for a 16-c.-p. lamp), and that the supply is at 110 volts. The current taken by a 16-c.-p. lamp will therefore be $\frac{64}{110}$, or ·58 ampère, and I have worked out the current in each circuit on this basis, the aggregate being 60·9 ampères. In calculating the size of the branch main cables and the branches several considerations come in. The insulation will be softened and damaged if its temperature is allowed to rise unduly high, and 130° Fahr. is the general limit allowed. The wires should therefore be large enough in this country to reduce electrical heating almost to the vanishing point. The ordinary rule-of-thumb is to allow a 'current density' of 1,000 ampères per square inch cross-sectional area of copper, though this is often too great an allowance, for reasons to be presently explained. You will see, however, that on this basis a No. 18 wire, having an area of ·0018 square inches, may be allowed to carry 1·8 ampères; a cable of 19 strands of the same wire, having an area of ·0358 square inches, will carry 36 ampères. If avoidance of heating were the only consideration—and sometimes this is so—then small wires might safely be allowed a higher current density than the above, for they have proportionately more surface to radiate the heat away. In fact, the Institution of Electrical Engineers allows a No. 18 wire to be loaded up to 3·1 ampères even in a situation where the external temperature is over 100° Fahr., and about 50 % higher still in a cold place, their formula for all sizes of cable being Current $=2\ A^{0.775}$, where A is the area in 1,000ths of a square inch and the insulation is of prescribed radial thickness, *i.e.*, 30 mils + $\frac{1}{10}$th the diameter of the conductor.

But since the resistance of a given sized conductor is a fixed quantity, the volts lost in it will rise as the current increases; this is a new factor altogether, and often greatly modifies one's calculations. When a current giving a current density of 1,000 is passing through a conductor, there is a drop in pressure of about 2½ volts per 100 yards length. If therefore all the wires are calculated on this basis, and the conductors running to and from the most distant lamp aggregate 150 yards (as may often occur), the total drop at that lamp will be 3¾ volts when all lamps are alight. Therefore the lamp will only get about 106 volts in place of 110, and as the candle-power varies with 6th power of the E.M.F. you will

see that this makes a good deal of difference. The allowable drop of volts in indoor wires is generally fixed at 2 per cent. of the standard pressure, *i.e.*, 2·2 volts in our assumed pressure of 110.

Returning now to our installation, for each of the four branch circuits a branch main must be run up to the distributing point, and no lamps at all should be taken off from it even though a light should be required close to where it runs. Nor should there be any joints whatever in these wires, unless it happens that the length is greater than that of a coil of wire,* which is unusual. Now these four sets of branch mains should each be independently controlled at the main switch-board, so that any one circuit may be absolutely disconnected from the rest when desirable. To effect this each has a cut-out and a switch on each pole, and main cut-outs and switches for the whole aggregate current need not therefore be used; the board becomes then a 'main distributing board' in place of a main switch-board The outside mains are brought to two 'bus bars' of copper on the back of the slate, and from terminals on these bars cables are taken to the various circuits on the front. (If, however, the supply is obtained from a public company, they must nevertheless put in main cut-outs on both poles for the protection of their system and of other consumers, and such cut-outs will be sealed by them and under their sole control.)

Branch main A carries 17½ ampères and has a run, lead and return together, of 120 feet of cable. In this short length the drop in volts at 1,000 C. D. (current density) will be just 1 volt, which allows a more than ample margin for loss in the lamp leads, etc., so we may take this figure. The area of our conductor should therefore be about ·0175 square inch, the nearest standard sizes being 7/17 and 19/20, of which the latter is generally kept in stock by contractors.

Branch main B carries 8·7 ampères and has a total run of 200 feet. At 1,000 C. D. the drop will be 1·7 volts, which is rather above the limit of our allowable loss. However, the nearest convenient size of wire to use is 7/18, which allows a good margin and causes a drop of only 1 1 volts, the next smaller size, 7/19, being seldom available.

Branch main C carries 11·6 ampères and has a total run of 360 feet, so evidently 1,000 C.D. will give us much too great a drop, *i.e.*, 3 volts. We will take 1·6 volts as the allowable drop, in which case $\frac{1·6}{11·6}$, or ·138 ohm., is by Ohm's law the required resistance of 360 feet of the necessary conductors. Now, 1 yard of copper 1 square inch in area has a resistance of ·0000215 ohms. Therefore by proportion the area of copper that has a resistance of ·138 ohm is $\frac{·0000215 \times 120 \text{ (yds.)}}{·138}$ = ·0213 square inch. Looking up the wire lists it is found that 19/20 is rather too small, and that it will be better to use 7/16, giving a drop of only 1·5 volts. Note that on ordinary occasions this wire will carry 23 ampères, but we use it to keep the pressure from falling too low.

Branch main D carries 23·2 ampères and has a total run of 500 feet. Assuming as before 1·6 volts drop the required resistance will be $\frac{1·6}{23·2}$, or ·069 ohm. For this resistance a length of 500 feet must have an area of ·0585 square inch, calculated as in the last

* The ordinary length of a coil is 110 yards.

instance. This comes in between 19/17 and 19/16, so the latter would generally be chosen, giving a drop of about 1·2 volts.

This brings us to the consideration of the 'branch distributing boards' for the four circuits, which will all be of the same general pattern, differing only in their size. The branch mains will be brought to two bus bars on a slate panel, just as in the case of the main distributing board, and terminals will be fixed along these bars to take off the lamp circuits. The number of lamp circuits will naturally depend upon the distribution and number of the lamps; each group will be protected by cut-outs on both poles at the branch distributing board, and in some cases it is convenient to have the switches mounted on the same slate also, though generally they are preferably placed near the lamps they control.

The best form of branch distribution board is that in which the fuses are mounted on porcelain bridges, which can be fitted in or removed in a moment. As at present made, however, the bridges are not sufficiently arched for 220 volt work, so that the blowing of a fuse may rupture the porcelain. Indeed I have had a case where the two adjacent bridges were also broken, but in this instance the fuse melted owing to a short circuit in the leading-in wires of a chandelier.

Let us take the branch circuit B, and trace out the fitting up of its 15 lamps. I have endeavoured to save confusion in the following diagram (Fig. 45) by the avoidance of lines crossing one another as far as possible, but it is concluded in each case that the two wires of a circuit are run in casing or tubing and cross where necessary in the manner I have already explained to you.

We will assume our 15 lamps to be taken off the branch distributing board from five sets of cut-outs, which I have numbered 1 to 5:—

No. 1 has a single bracket.
,, 2 has two pendants.
,, 3 has a 7-light electrolier.
,, 4 has two wall sockets for portable lamps.
,, 5 has a 3-light pendant.

You will remember that a smaller conductor than one No. 18 is only allowable under special circumstances, and in actual practice this wire is used for the great majority of lamp circuits.

No. 1 branch is entirely simple; two No. 18 wires are taken from the fuse terminals, one of them is led down the wall to a convenient spot for the switch, and then up again in the other groove to rejoin its companion, and the two run up the tube of the bracket to the lamp-holder. The casing has of course been previously run, and all precautions with regard to it have been attended to. The wire has only ·6 of an ampère passing through it, so even if there were 100 yards of it, the drop in volts would be only ·8, which, added to the drop in the branch main, 1·1, would give a total drop of 1·9 volts at the lamp. Unless the distances of the lamps from the distributing centre are very excessive, the 1,000 C.D. rule may be safely followed for lamp circuits, and I am doing this in the succeeding cases.

No. 2 is capable of being done in several ways. In the diagram (Fig. 45) I have shown by far the best method, and it is really the least

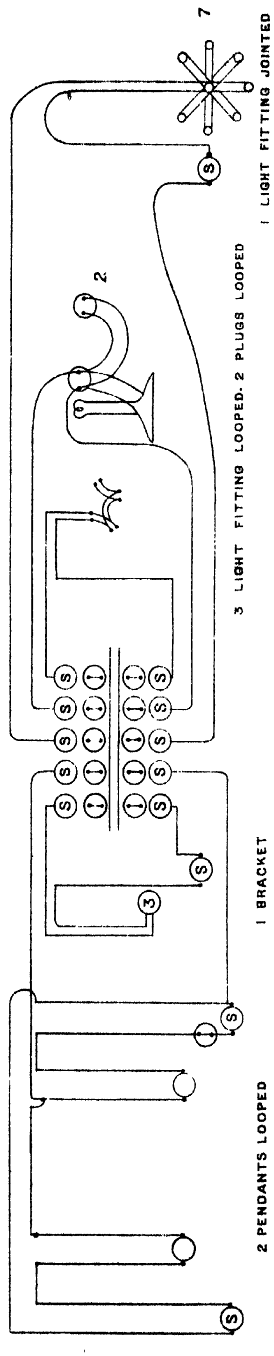


Diagram of circuits from a branch distributing board.

Fig. 45.

trouble too in the end. It will be seen that there are no joints, the terminals of the fittings taking their place, and yet the two lamps are quite independent of one another, should either fail. The lamp leads are taken one to the first ceiling rose and the other to a switch terminal, from which points the two lamp circuits have their own separate wires, and since the two wires entering the first switch terminal are of the same polarity, they can be run in the same groove of the casing—suitably enlarged. There is little harm in such "bunching" even of several wires of the same polarity, but wires of different polarity must never be bunched or even allowed to touch in casing; this is only allowable in fire-proof tubes. If it is thought necessary to have a cut-out on each individual lamp, one can be placed between the switch and the lamp (as shewn) without affecting the other lamp, though this is not generally necessary. Three or four lamps can be equally easily wired in this same way. One pitfall, however, must be looked out for, namely, that if the looping back wire at the first or any switch is put in the wrong terminal of the switch, then the furthest lamp will only light when the nearer one is also on. We need not work out the fall of potential in these lamp leads, since the current of two lamps still leaves the 1/18 under its carrying capacity at 1,000 C.D., and the length of wire is not likely to be sufficient to cause a heavy drop.

The other way of doing No. 2 lamp circuit is to run two wires to the furthest lamp and tap off the near one with joints (Fig. 46).

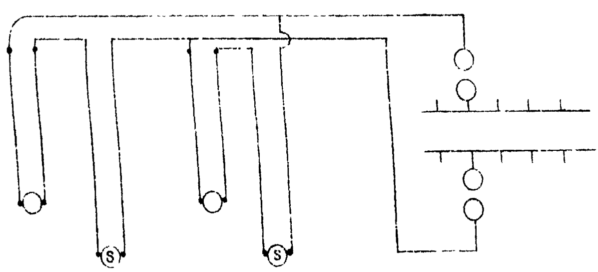


Fig. 46.

It is the fact of having joints that makes this method inferior to the other. Provided the wires are all of the same size and the fuse in the distributing board is small enough to protect the flexible wire of the pendant, there is no necessity to put any fuse wires in the ceiling roses or at the joints. A good many electricians seem to think it necessary to pitchfork a cut-out into every possible corner, forgetting that there is as much danger in the multiplicity of fuses—which *may* fail—as in their scarcity. As an example of the possible danger of cut-outs, even when not in excess, I recollect coming across a box of branch cut-outs in a rather inaccessible corner of a house, each bridged across with copper wire thicker than the conductor. I ascertained that the fuses had blown several times, and that the owner had consequently taken em all out and put in these bridges to save annoyance. Here cut- gave a false security indeed, and might have caused a fire.

Taking No. 3 circuit (Fig. 45) we find that it has a 7-light electrolier on it, the current being therefore just over 4 ampères. A 7/22 cable has an area of ·0043 square inches, and will therefore be the size to use for any reasonable distance. If the electrolier is more than about 65 feet away, a larger size—7/21½ or 7/21—will be necessary. For our total allowable drop is 2·2 volts, of which the branch main accounts for 1·1, and you will find that 130 feet run of 7/22 with 4 ampères about takes up the remaining 1·1 volts. For wiring this electrolier there will probably be no choice of method; each of the seven branches must be brought to the centre and jointed on to the conductors. The branches will of course be of smaller wire, special No. 20 being allowable for this purpose only; it is generally known as 'chandelier wire' and made of as small over-all dimensions as possible.

Circuit No 4 serves two wall sockets, from which portable lamps will take their supply. This is a very simple arrangement, the wires being taken to the first socket, whose terminals then act as the start of a new circuit for the next, and so on if more than two are required.

Circuit No. 5 serves a 3-light pendant, which will be hung from a ceiling rose. The two No. 18 wires will run to the terminals of this, one being diverted to the switch and back. No fuse need be used in the ceiling rose, since both poles are protected at the distributing board. The flexible will run to one lamp-holder; from its terminals a short length will loop back to the second holder, and this again will serve the third holder, thus avoiding all joints.

General notes on house-wiring.—This completes the survey of our hypothetical installations, and I will now add a few notes and hints on house-lighting work in general. In deciding what lights to put into a room, you must bear in mind the use to which it is put and the convenience of those who use it. Thus, as a rule, one light at least should be controlled from near the door by which the user will enter, or in some cases outside it, and switches should on no account be hidden away where they are difficult to find.

It may be desirable to be able to switch a lamp on or off from two separate places, as, for instance, to be able to light a staircase lamp downstairs and switch it off upstairs. This can be done by means of an extra wire and a form of 2-way switch as shown in the Figure 47. If

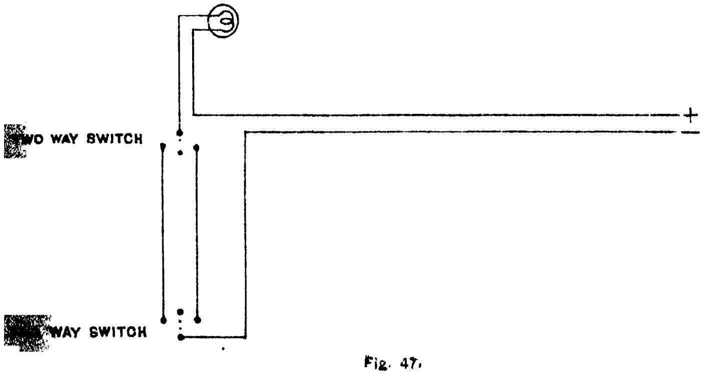


Fig. 47.

the light is off, either switch will put it on and *vice versâ*. Casing with three grooves can of course be made to take the three wires where they run together.

To light lamps on a dining-room table, without having wires stretching across to it, a wall socket must be sunk flush in the table, the wires being taken up a leg or up a pipe in the centre. To insert the plug from the top means cutting small holes in the cloth, which is somewhat objectionable, and special plugs with fine needle points are now made for the purpose.

In the wiring of Government House, Calcutta, it was essential to provide for the considerable extensions inseparable from a large installation, in the shape of extra lamps or wall sockets, and in fact many such additions have already been made. Only 500 current density was allowed in the mains and sub-mains and 1,000 in the lamp leads; the distribution was carried out almost entirely with No. 1/18 S.W.G., so the latter figure left a large margin on the current allowable under the I.E.E. rules, which can now be drawn upon safely. From any given branch cut-out not more than 6 lamps ($220^{v.}$) of 16-C.-P. (presumed throughout) were run in the first instance on a 1/18. To avoid all joints 'connectors' were used, *i.e.*, bow cut-outs employed merely as terminals for tapping off lamp leads, with a thick wire in place of a fuse. The idea has proved most fertile, for when an extra lamp has to be put up it is only necessary to take off two wires from the nearest pair of connectors; and, provided a proper record is kept of every branch circuit and the additions made to it, there is no fear of overloading any conductor or of losing too many volts. It appears to me that manufacturers might with advantage put on the market a connector for this class of work; it could be made quite small and inconspicuous, and consist merely of two terminals mounted on a strip of metal and enclosed in porcelain.

In running wires it is best to keep to a uniform system for the leads and returns (or + and — wires). The usual rule is to run Leads to the Left when vertical, and Lowest down when horizontal, Returns Raised and to the Right.

In settling the height of a lamp recollect that the quantity of light received on a given surface varies inversely as the square of its distance from the source, and that it is not therefore wise to put the lamps higher than necessary. Munro and Jamieson give the following useful rule:—

"For very good class-room lighting each 16-C.-P. lamp 7 feet above floor level allow 50 square feet; for sitting-rooms 80 square feet; bed rooms 100 to 150 square feet; corridors 200 square feet."

Many little contrivances have to be devised on the spur of the moment in actual work. Thus, wires have to be taken along a ceiling divided up by carved beams, where there appears no room for casing, but perhaps by splitting the casing into two parts and running the halves symmetrically on either side they will not be noticeable. Much may also be done by neat painting. Or, again, casing has to be run along iron beams, and special clips must be devised to hold it on.

Examination and testing of installation.—Having seen how to put up an installation, let us now proceeed to put ourselves into the position

of critics and consider how to examine and test it before passing it. Conscientious contractors test their own work as they go along and allow no bad point to pass, but all contractors are, unfortunately, not conscientious.

The simplest and most necessary tests are those for 'continuity' and 'short circuits,' *i.e.*, for seeing that there is a complete circuit from each pair of fuses through its lamp, and that there is no complete circuit through any other route. It may easily happen that the wireman gets into a confusion with his wires and couples some wrongly, so that in one case a lamp is not coupled in at all, or in another the wires are coupled across without any lamp. The latter case constitutes a short circuit, and if coupled to a 'live' circuit produces fireworks, probably burning the fingers of the operator, and a course of experiments in coupling up, with the inevitable short circuits interspersed, is an excellent training in carefulness. The instruments usually used for making these simple tests are either a 'detector' or a 'magneto bell.' The former consists of a little galvanometer coupled in series with a portable battery, so that when the ends of an otherwise closed circuit are connected to its terminals the current flows and deflects the needle. The latter consists of a trembling bell and a small permanent magnet magneto-machine in series, so that if the machine is revolved the bell will ring through any closed circuit that may be connected across its terminals. With either of these instruments it is a simple enough matter to identify the two ends of one circuit amongst a number of wires mixed up, often a necessary operation.

Finding continuity all right and no short circuits, the next thing is to examine the work and see that it has been properly done. There are a number of different sets of rules to go by, so many, in fact, that any one armed with three or four of the chief ones and no practical knowledge would find himself in a quagmire of apparent contradictions. Big installations are usually erected to a Consulting Engineer's specifications, but the ordinary practice is to specify such and such rules to be followed. If the power is to come from a supply Company, that Company will have its own set of rules and expect them to be kept; if the building is insured, the Insurance Company will expect their rules to be observed, many Companies having their own code; while contractors in general prefer to follow the recommendations of the "Institution of Electrical Engineers." Uniformity is very badly needed, and at the present moment the Institution is revising its code of "General Rules" and endeavouring to formulate a set that will suit everyone and be generally accepted. As these may not be issued for some time, I am adding in Appendix III (by special permission) the rules recommended for India by the "Calcutta Fire Insurance Agent's Association" which were drawn up by myself to suit local conditions. The chief points for examination are the system of wiring, quality of material, ...ts and whether they have been avoided as much as is ...ible, position and fusing of cut-outs, erection of casing ..., method of running through walls or in other hidden ...d proper insulation of fittings by means of blocks. Wiremen, ...uman, are generally apt to scamp work—if at all—in places ...re it is unlikely to be examined. Under a floor, where a fault or

short circuit would be a far more serious matter than on a wall, you may sometimes find casing with no capping, and large gaps between the pieces, or even no casing at all; joints in profusion and with no pretentions whatever to be either electrically or mechanically decent, much less perfect; and pieces of small badly insulated cable used to make up a shortage of a much bigger conductor. Do not imagine that these are things you will come across every day, but recollect that they have been perpetrated, both in England and India, and assuredly will be again.

Examine the connections at all switches and other fittings. A screw left slack means that the wire does not make proper contact; this introduces extra resistance, produces a drop in volts not allowed for, causes the terminals to get hot—possibly dangerously hot—and may sometimes make the lamp go out unexpectedly, owing to an intermittent making and breaking of the circuit. In lamp-holders see that the strands of the flexibles all enter the terminal holes, for a few straggling about may cause a lot of mischief through a short circuit inside the holder.

Presuming everything passes examination, the next thing is to test the insulation resistance of the circuit. Two factors come in here, the insulation resistance between one wire and the other when everything is in place except the lamp, *i.e.*, between poles, and the insulation resistance of the whole circuit, including lamps, from earth. If good material has been used and the latter test is satisfactory, the former is not likely to be bad. A number of different instruments are sold for making these tests, the best known and handiest being the Silvertown testing set, of which you will find a full description in the 12th edition of "Munro and Jamieson's Pocket Book of Electrical Rules and Tables." The method is to compare the unknown resistance with a known one of 5,000 or 10,000 ohms. An important point is that the battery used for the tests should give at least as great, and preferably a greater, pressure than that of the supply; the Institution of Electrical Engineers specify double the working pressure and, where possible, this should be used.

To make the test between poles all lamps must first be taken out, all switches put on and fuses examined. Two wires are then taken from the main terminals to the instrument, these being kept well apart and away from damp floors or walls.

To make the test to earth, the lamps are put in and the other fittings remain as before. A 'line' wire is then taken from *either* main terminal to the instrument, and another wire is taken from the instrument and connected to 'earth.' The latter process generally means making the connection to a gas- or water-pipe, since these are generally in connection with earth, but it is equally good to put it in thoroughly moist earth or down a wet drain. If the test is *far* higher than would be expected, it is well to change the earth, or else to connect one of the terminals under test through another wire to a different earth to see if there is a deflection, for even with the best intentions you may happen to fix on to a dead end of disconnected gas-pipe. I once took a test that appeared suspiciously good, my earth being a gas-meter kindly connected up for me by the consumer—an electrician. On

examination I found he had disconnected the gas-pipes below and mounted the meter on porcelain insulators!

Various authorities give various figures as to the insulation resistance an installation should have, but provided the work is thoroughly well done, it is not a point one can be very exacting about. This is especially the case out here, where a test often totally alters in a day or two according to the weather. If an installation will not test up, a few dry days will probably put it right in this respect; and no rules which I have seen specify what the humidity should be on the day of test. If the material is good and the work has been carefully done some margin can be allowed, but where the work appears at all "shoddy" the full test should be exacted. The greater the number of fittings and the length of wire, and therefore generally the number of lamps, the lower the insulation must naturally be. The I.E.E. specifies the required insulation to earth as 10 megohms (*i.e.*, 10,000,000 ohms) divided by the maximum number of ampères required for the lamps and other appliances, and suggests the repetition of the test after 15 days' working. This may be taken as the best guide, though such a test is never likely to be obtained here during the rains, whereas a far higher result is not unusual in the dry months.

If it is necessary to test the installation for drop in volts, to see that this does not exceed 2 per cent., all lamps are switched on and the pressure is read with a volt-meter first at the main switch-board and then at the terminals of the most distant lamp-holder, the lamp being removed. Several readings of each should be taken successively to get an average value.

Cost of internal wiring.—Before leaving this installation let us look for a moment at the matter of cost and make rough estimates of fitting it up and of maintaining it. It is not necessary for me to go closely into details in this matter, but I will take rather the figures which are generally quoted by local firms for the best class of work. It is customary to divide up the estimate into two parts—plain wiring and fittings. The former generally includes distributing boards, casing, cables, switches, cut-outs, wall-plugs, ceiling roses, lamp-holders, lamps, plain shades, all fixed completely—in fact everything except fancy fittings, such as brackets, electroliers or table-lamps, which come under the latter head. Plain wiring will be quoted at so much a 'point' or ultimate circuit, whether there be one or more lamps at it. A 2-light point costs naturally more than a 1-light point, but far less than two separate 1-light points, since only one set of wires, switches, &c., are needed. The ruling price per 1-light point in Calcutta varies from Rs. 20–24 per point for work in houses, and for a higher number of lights per point the following prices are probably about what will be quoted:—

			Rs.
2-light point	...	...	26–30
3- " "	...	...	31–35
4- " "	...	...	36–40
5- " "	...	...	40–46
6- " "	...	...	44–52
7- " "	...	...	48–58

Assume that the 105 lamps are divided up as follows:—

				Rs.			Rs.
1	7-light	point	(electrolier)	... at 49	...	=	49
2	5- „	„	(„)	... „ 41	each	=	82
6	3- „	„	(3-light pendants)	... „ 32	„	=	192
6	2- „	„	(pendants)	... „ 27	„	=	162
58	1- „	„	(pendants, brackets, table-lamps, &c.)	... „ 21	„	=	1,218
				Total	...		1,703

and we arrive at a figure of Rs. 1,703 for the plain wiring of the installation.

Fittings cost anything the buyer chooses to pay, according to the quality and amount of ornamentation, from Rs. 2 for a plain 1-light bracket upwards. Assuming that we require quite plain fixtures I have taken the prices from a catalogue for about the least expensive of each class of fittings, with suitable shades:—

				Rs.			Rs.
1	7-light	electrolier	...	... at 90	...	=	90
2	5- „	electroliers	...	... „ 70	each	=	140
6	3- „	pendants	...	... „ 6	„	=	36
6	2- „	„	...	... „ 4	„	=	24
58	1- „	brackets or pendants		... „ 2	average	=	116
				Total	...		406

The complete installation from the main switchboard will then cost Rs. 1,703 + Rs. 406, or Rs. 2,109. Now I do not doubt that fiıms could be found who would willingly undertake the work for a good deal less, unless bound down by a very strict specification to do good work. My figures are fairly liberal no doubt, but there is a limit below which good werk could not be done, and yet leave a reasonable margin for profit, taking into account office expenses, supervision and so forth, as contractors must do.

Lastly, let us see roughly what the current will cost us. A fair assumption is that eveıy lamp will be alight about two hours a day, for some will hardly ever be used, and while others will perhaps be on four hours or more. A 16-C.-P. lamp takes 64 watts, therefore 105 will take 6,720 watts, or 6,720 watt-hours per hour Therefore per day (assuming two hours' use) they will consume 13,440 watt hours, or 13·4 Board of Trade units of 1,000 watt hours. In Calcutta the price is eight annas a unit at present, so the cost would be Rs. 6-11 a day. In Darjeeling the price is four annas a unit, or half this figure. In private installations, having their own generating plant, it will vary from about six annas (exceptional) upwards. Of course we have assumed a fairly large installation, but it is quite as easy for you to work out the figures for one of five lamps; and in practice also 8-C.-P. lamps will of course be used very considerably, and they take but half the power of those assumed.

High Voltage supply.—The Calcutta Electric Supply Corporation sell current at an E.M.F. of 225 volts to consumers; if therefore our installation is there, certain modifications have to be made. The current in every case will be just about half what I have given above, and the cables can have half the cross-sectional area of copper, except that the lamp leads would not be smaller than No. 18 for mechanical reasons. Thus the drop in volts will be about the same as before; but since the pressure is doubled the percentage drop is halved, a fact of which the full importance will be realized when we study the Supply Company's outdoor mains system.

Even greater care must be taken with the wiring of a high voltage installation, and the switches and cut-outs must have a longer break between terminals and better insulation generally than if the pressure were 110 volts only. From the consumer's point of view there are certain distinct disadvantages in obtaining supply at 220 volts, notably that the lamps have a shorter average life and a lower efficiency than those for 110 volts. Against this we must put the fact that the price per unit is likely to be lower, since the supply can be economically given over a much larger area and to a much greater number of houses.

Rotary electric fans, &c.—Electric fans are now being extensively put up in Calcutta houses to take the place of *punkhas*. The motors are of course made suitable to the Supply Company's pressure, which is 225 volts, or double that of our model installation. Each fan takes about ·3 ampère, or about the same as a 16-C.-P. incandescent lamp for the same pressure; for permanent work a fan would therefore be wired in the same way as any single light fitting, and would be kept on a circuit of 1/18 by itself. Many fans, however, are hired out at a fixed price per month, and are liable to be taken down at any time. In such cases the wiring is generally of a temporary character, the usual method being to run a twin flexible along on insulators. Provided this is well insulated with vulcanised rubber and kept in dry places only, I see no objection to the system *for temporary work*, since such a wire will have a life of some years. Note with regard to these fans that when the blade is set at an angle of 45° they travel slowest and use most current; for the quicker a motor goes, the greater the back E.M.F. it develops, and therefore the less current passes through. The blades can usually be set either for comfort or economy according to taste, but none of the fans I have come across seem suitable for any other use than over a bed or an office table, for they all throw a cylindrical gale underneath them and very little air at all more than a few feet away from that cylinder; possibly fans with flat blades curved vertically upwards would distribute the air more evenly.

I do not think that electrical heating is likely to be adopted out here except possibly in some of the hill-stations in winter, and neither are there any signs of electric cooking coming in, but while on the subject of house work I may with advantage just touch on these. Most apparatus of this description consists of a series of wires buried in and insulated from one another by a special enamel—generally vitreous. The resistance of the wire is so calculated that under given conditions of E.M.F. a large enough current will pass to heat the wire as highly

as it will stand, without its physical nature being altered. For to heat up a given mass of the enamel to a given temperature requires a certain quantity of heat, and the higher the temperature of the wire the less there need be of it in order to give off the heat in a given time; so that less power will be expended and greater efficiency will result. And looking at it in another way, since the heat obtainable through a given resistance varies as the square of the current, it is evidently economical to keep the temperature of the wire high.

Mill lighting.—So far we have dealt with private house work; for mills the question of appearances need not come in, and the work while still good electrically can be made cheaper. Thus long lines of lamps will be required with only short lengths of wire and casing in between them, and all controlled from one end by one set of gear, while the very plainest fittings and shades can be used. A fair figure for mill lighting is about Rs. 17 to Rs. 18 per point inclusive of everything up to the main switchboard.

Special precautions against fire have to be taken in mills containing either peculiarly combustible goods or corrosive liquids, or gases by which the insulation may be destroyed. In such cases a tube system is generally the best, care being taken to protect the outside of the tube and the joints in it with paint, and to examine the work periodically.

Lights for out-of-door use have to be placed in perfectly water-tight lanterns, of which there are many patterns. The plainest consist of a U-shaped globe with a flange which is gripped against a flat India-rubber band on the metal back-plate, the wires being led in through a tube at the back. If fixed on the walls of a house to give light outside, it is best to run the tube right through the wall; if fixed on poles or trees, the conductors can be carried there in several ways, which we can more conveniently discuss when dealing with the overhead mains at Darjeeling.

LECTURE IV.

PRIVATE PLANT.

We have as yet assumed in all cases that electric power is ready to hand at the point where we require it: I shall now consider the means of generating it and bringing it to that point, and first in the case of a private plant, such as would be erected for a large house where no public supply is available. Still keeping to the same installation of 105 lamps we will now study these further matters.

Mains.—Let us assume the engine-house to be at a distance of 100 yards from the main distributing board in the house, the total current being, you will remember, 61 ampères. Now a drop of a few volts in this main at full load is not a serious matter, for the dynamo can be regulated to compensate for it and give a steady pressure in the house. We will allow 3 volts to be lost, and the resistance must therefore be $\frac{3}{61}$ or ·049 ohm for 200 yards of lead and return. The wire lists show that 19/14 with a resistance of ·025 ohms per 100 yards exactly suits the case, or if a solid conductor is for preference used, it must have an area of about ·103 square inches. Evidently we may carry our main either over head or underground, the chief advantage of the latter method, namely that nothing is visible, usually outweighing those of the former. We will consider each in turn briefly, leaving the further consideration of the subject until we come to deal with public supply.

If the main is overhead, bare solid copper wire will generally be used. For a distance of only 100 yards, such as we have, one post at the engine-house and one half-way will probably be sufficient, the house itself being used as a support at the far end of the line. Porcelain insulators held by iron brackets will support the wires, which will be bound on to them with smaller wire. At the terminal points the wire will pass right round the insulator, and then be bound and soldered up. For heavy wire such as this shackle insulators are best at the terminals, since the tension is apt to pull over an ordinary supporting insulator (Figs. 48, 49). The leading in wires at both ends of the line would be 19/14 insulated, and would be taken through the walls in compo piping. Insulated overhead lines will be dealt with presently. In India I consider they are not advisable as a general rule, owing to the rapid deterioration of insulation exposed to the weather.

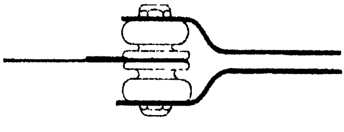


Fig. 48.

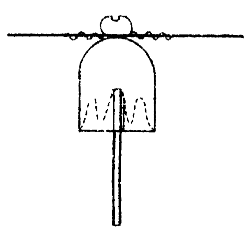


Fig. 49.

If underground construction is decided on 19/14 insulated cable will be used throughout. A trench must be dug along the route

and a substantial trough of teak, concrete, or iron placed in it. The wires will then be laid side by side in this, spaced from one another and from the trench by bridges of teak, and the whole then filled in with melted bitumen or pitch. Other systems there are also, some of which will be considered later on if time allows; the one I have here mentioned is, in my opinion, the most reliable for this country, and I may mention that the conductors connecting the old Jablockhoff arc lamps in the Eden Gardens here were so laid many years ago, and still give no trouble.

Main switchboard.—In the engine-house the main cables come to the switchboard, and assuming that the lights are to be fed directly from a dynamo, without a battery, this will be quite a simple affair (Fig. 50).

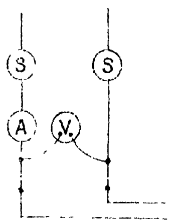


Fig. 50.

Each of the leads from the dynamo comes to a 60 ampère cut-out; this consists of two terminal blocks of copper about 3 inches apart, with thimbles at the back of each for the wires, and nuts and washers in the front for the fuse. The latter will be of pure strip tin, say No. 22 B.W.G., tapered towards the centre until the right cross-sectional area is arrived at. It is neither wise nor necessary to cut main fuses too fine, and a margin of 100 per cent. will still protect the cable from all damage. According to Preece's tables a current of 120 ampères (100 per cent. above the actual) will just fuse an area of ·024 square inches of tin, and since the thickness of No. 22 B.W.G. is ·028 of an inch, a width of 1 inch will practically meet the requirements. After passing through the cut-outs one conductor will be connected in series with the ampère-meter which measures the main current, and then each conductor comes to its main switch, to the open terminals of which the outdoor main is connected. We have still left the voltmeter out; the two terminals of this are connected by short leads to the thimbles of the two cut-outs, so that it is connected across the circuit and in parallel with the lamps. It is connected to these points so that the volts can be read even before the main switches are closed, the voltmeter making a closed circuit on its own account. All this gear is of course mounted on a suitable base, usually of slate.

The short lengths of wire from the dynamo to the cut-out are generally run in wrought-iron piping, which can be previously fixed under the floor level; provided the run is fairly straight, and sharp bends are avoided, it is easy to draw in the wires.

Dynamo.—We must now turn to the question of the dynamo, and see what will suit our purpose best. There is no question as between

continuous and alternating current, since for many reasons a private installation of this character will almost invariably be run with the former, but the dynamo may be either shunt-wound or compound-wound. If there is any likelihood of batteries being added to the installation later on, a shunt-wound machine should be used, since it is not liable to have its polarity reversed and is capable of most excellent regulation by hand, but as we are at present assuming no batteries, the compound-wound dynamo will suit our purpose better, since it is self-regulating. A compound machine when driven at constant speed will have the same external, or terminal, E.M.F. whatever the current is; with a shunt machine there is a drop in E.M.F. as the external resistance is lowered, and in a compound machine this is just compensated for by the series turns on the magnets, whose magnetising power increases of course with the external current. But in the present instance we require more than that, since we wish to make up a loss of 3 volts calculated to occur in the mains. Our dynamo will have to be slightly 'over compounded,' *i.e.* have a few more turns of main than are necessary to just neutralise the drop, and so that it will give 113 volts at full load and 110 at light load or on open circuit. The dynamo must be capable of giving about 60 ampères, though as all the lamps are never likely to be on simultaneously a rather smaller size will do, especially since a good modern dynamo can be safely overloaded for a short time to the extent of 15 per cent. or even more.

Prime-mover.—We may drive our dynamo by—

(1) A turbine.
(2) An oil engine.
(3) A gas engine.
(4) A steam engine.

The turbine method can be dismissed at once, since it will be more suitably discussed when dealing with central stations, and is, unfortunately, seldom practicable in private installations.

In comparing the relative cost of coal, gas and oil as fuel for the three classes of engines the following figures (from a paper recently read before one of the scientific societies) give the approximate consumption for small private plants.

Coal	per unit	12 lbs.
Gas	" "	50 cub ft.
Petroleum	" "	$1\frac{3}{4}$ pints.

On this basis, and taking the prices approximately ruling in Calcutta, this works out as follows:—

With coal at annas 7 per maund,	cost of fuel per unit is	1	anna.
" gas " Rs. 6 " 1,000 c.ft.	" " " "	5	"
" oil " annas 7 " gallon	" " " "	$\frac{1}{2}$	"

For very small powers an oil engine is a most convenient prime-mover. It is fairly simple in construction and action, and any one of ordinary intelligence will soon learn to work it. The usual cycle is that the piston on its forward stroke draws in a certain quantity of air and a proportionate amount of the heated vapour of petroleum; on the return stroke this mixture is compressed by the piston, and then at the commencement of the second forward stroke it is ignited, and

the explosion gives the impetus that does the work. The next back stroke clears out the products of combustion and prepares the cylinder for receiving a new charge Thus in two complete revolutions there is only one impulse given to the piston, while the flywheel has to keep the speed steady during the remainder of the time, despite that external work and internal compression are going on. Inevitably the speed slows down a little and then bounds forward at the explosion, and this change of speed affects the E.M.F. of the dynamo and shews as a pulsation at the lamps. Consequently it is necessary to fit a heavy flywheel pulley on the dynamo, and except in very small sizes this necessitates a third or outer bearing to support the extra weight. Up to about 5 B.H.P. the engine and dynamo flywheels render the flickering almost unnoticeable, but in larger sizes it is palpable and objectionable. If therefore an oil engine is chosen as the motive power for our larger installation, we must use batteries in order to keep the light steady, a point which I shall consider presently. The installation of electric light at the new Government House in Naini Tal is run from batteries, an oil engine being used as the motive power for the charging dynamo.

A gas engine presupposes either a public gas supply at hand or a special private one for the purpose. The latter course has been sometimes adopted, as it is probable that a more satisfactory effect can be obtained through a gas engine and dynamo than by burning the gas direct. Coal gas, water-gas and oil-gas each have certain advantages, and Dowson and other generating systems have been evolved to obtain them to the full. Where a public supply happens to be available, there is much to be said in favour of these engines for small powers, but the same limitations apply as in the case of oil engines. Recently, however, improvements have been made in gas engines which may render them almost rivals to steam in places where gas is very cheap, and American firms are now making them of great size compared with what had previously been done.

On the whole, especially if we are to run without batteries, a steam engine will suit our present purpose best. The electrical output of the dynamo is 113 volts × 60 ampéres= 6,780 watts =9·1 E.H P. Now dynamos are listed in the maker's catalogues which will give 6,780 watts at any speed from 360 revolutions a minute up to 1,200. But whereas the former will require about 14½ Belt H.P., the latter will need not more than 11½, and the former will also cost far more than the latter, since it is a much larger machine. Now there are two ways of driving a dynamo; it may either be coupled direct to the crank shaft of the engine, and therefore driven at the same speed with it, or it may be driven by a belt at any speed according to the gear ratio. The slower of the above-mentioned machines would be direct-driven by an engine running at 360 revolutions, whereas the smaller and fast revolving one would be belt driven. Those two methods can be discussed in turn.

Combined sets.—A direct-driven dynamo is mounted on an extension of the engine bedplate, the armature and engine shafts terminating in two half couplings which are bolted together. The speed of such a dynamo will be low by comparison, and it will consequently be

necessary to make it much larger than a belt-driven dynamo of corresponding power. A special class of engine has arisen for the direct driving of dynamos, the best known varieties being the Willans, Chandler, and Belliss. They are all high-speed short-stroke engines, with all working parts enclosed and special arrangements for lubrication, and I will devote a few moments to a short general description of each, without pretending to go into details.

The Willans engine was the pioneer of the class. Its chief feature is the valve gear, which is in the form of a smaller piston in the centre of the main piston; the piston rod is hollow, and the valve gear works inside it, the steam being admitted through ports round the rod. The eccentric is worked off the crank pin instead of the crank shaft, as is usual, in order that its motion may affect the valve gear relative to the moving valve face; it is placed centrally, the connecting rod being in two parts on either side of it. The engine is single-acting, so that the pressure is entirely downwards, and all parts are in constant thrust, consequently the crank shaft bearings are open entirely at the top. The crank chamber is completely enclosed, and is filled to nearly the level of the crank shaft with a mixture of castor-oil and water, into which the cranks splash at every revolution, this device ensuring that every part is well lubricated. There are inspection traps in the chamber through which the working parts can be examined when necessary. The crank chamber may get very hot through the leakage of exhaust steam into it, but the water in the mixture prevents the temperature rising above boiling point, and there are generally also cold water circulating pipes to keep it cooler than this. As the steam pressure acts only downwards, there is an enclosed air-chamber below the cylinders in the space in which the guide piston works. This chamber is opened to the atmosphere at the bottom of each stroke, so the compression is constant in amount and the loss of power is negligible, since the air expands again on the down stroke. This device prevents the engine from knocking itself to pieces and ensures smooth running even at such high speed as 650 revolutions. The governor acts on a throttle valve placed just beyond the separator; it is spring-controlled, and the springs can be regulated during working to alter the speed within fair limits. Some engines are fitted with variable expansion gear, either hand or automatic, since for an engine seldom fully loaded a great deal of steam will be saved by using an earlier cut-off, instead of throttling at the main valve. The gear is placed in the steam chest, which runs along the top of the lines of cylinders, and acts by slightly rotating a cylinder which fits over the continuation of each hollow valve-piston, both of these couples having corresponding rectangular ports placed diagonally. The parts of these engines fit like a Whitworth gauge; if a cylinder is put on an oiled face-plate and a piston dropped in, it will remain suspended by the air below it. The consequence of such workmanship is that the parts are perfectly interchangeable, and a new engine can generally be relied on to start without trouble and run continuously as long as it is needed. Willans engines may have one, two or three cranks, and may also be single, double or triple expansion. When there is more than one expansion the cylinders are placed

tandem fashion, so each bottom cylinder (low pressure) may have an intermediate cylinder above it with a high pressure cylinder again over that. Thus a 9-cylinder engine is by no means unusual, and, when this and the high speed are taken into consideration, you will see how compact such an engine must be for its power. For instance a 360-H.-P. Willans' engine together with its direct-coupled dynamo takes up only a space of about 19 feet by 6 feet.

Many of the foregoing remarks apply also to the Chandler engine, which is one of the very best for fairly small powers. It is also single-acting, with all moving parts constantly in compression, and it fully bears out its name of the "Silent" engine even when working at maximum load. A great many Chandler engines are used for steamship lighting for which they are particularly well adapted, owing to their simplicity and the small space they occupy.

The Belliss engine differs from the last two in being double acting. The adjacent lines of cylinders are worked from a single slide valve of special construction placed in between them. Lubrication by splashing would not of course be of any use in this engine, since the bearings have to be closed top and bottom; but a small oil pump inside the crank chamber is employed in forcing oil through a system of pipes to all the places where it is required, under a pressure of about 16 lbs. on the square inch. Though originally developed to suit the special needs of dynamo driving, these various types of engines are now employed in many other ways where high speed and direct coupling are desirable.

Belt driven sets.—A dynamo for belt driving will be run at a far higher speed than its direct-coupled equivalent, and will consequently be both smaller and cheaper. In the instances just given there would be a difference of about 100 per cent. in the prices. Should it be decided to drive the dynamo by a belt either from the engine pulley or through an intermediate counter shafting, it will be mounted on a cast iron bedplate which must be bolted down securely. A belt, however, gets slack in time through stretching, and to open it up and replace it after taking up the slack would be a tedious and recurring business. It is therefore usual to mount belt-driven dynamo bedplates on two 'sliding rails' with a slot in the centre; these rails are permanently bolted to the concrete or masonry foundation, or occasionally to timber beams, and if it is desired to take up slack in the belt, the dynamo holding down bolts are loosened and the machine is pushed forward a trifle by screws. This can easily be accomplished while the machine is at work, care being taken to move the dynamo parallel to itself, or the belt may fly off.

The lubrication of dynamo bearings, whether direct or belt driven, is now usually done by the use of self-oiling rings, which lie loosely on the centre of the journal and dip in an oil reservoir below, revolving slowly and carrying a stream of oil on to the journal. Sight-feed lubricators are gradually being superseded by these self-oiling bearings, which have the great advantage of using the same oil over and over again for weeks, thus effecting economy in both oil and attention. If the prime mover is a really good steam engine the turning moment is quite steady enough without any flywheel pulley on the dynamo,

even for large horse-powers, for even a simple one-crank double-acting engine will have two impulses per revolution instead of one impulse in two revolutions.

The engine may practically be of any class or make, so long as it has sensitive governors: vertical or horizontal, simple or compound, condensing or non-condensing, each in its way may be suitable. But good governing is essential; there must be no 'hunting' up and down, no racing when a lot of lamps are switched off, no pulling up dead when a load is put on. And when normal work is being done, no ordinary alteration of the load should make more than about 3 per cent. difference in the speed, or the lamps will be giving their wrong candle-power to a noticeable extent.

Boilers.—For supplying steam to the engine of a small installation, whether it be a high-speed or an ordinary one, a locomotive type boiler will generally prove the most satisfactory; they steam up fairly quickly and are economical. The steam pressure depends of course on what the engine is built for, a compound or triple expansion engine employing a higher pressure than a simple one. The latter will generally be built to work at from 60 to 100 lbs. per square inch, and the former from about 100 lbs. upwards to 200 lbs. I need not here enter into particulars as to engine-room equipment, which scarcely comes within the scope of these lectures.

Accumulators.—Batteries must now claim our attention for a time, since they will be found in a majority of installations; secondary batteries, that is to say, or accumulators so-called. The difference between these and primary batteries is not really so great as generally appears. In the latter, plates of two dissimilar metallic or semi-metallic elements are placed in an electrolyte, which readily attacks one of them on the completion of the external circuit, and oxydises or otherwise alters its nature; in the former two plates of the same metallic element are placed in an electrolyte, and current is passed through them from an external source until they are altered and become chemically different. Thus a charged secondary cell is practically the same thing as a primary one. The only secondary cells of any practical value are those in which the plates consist of lead, in some form or other, in an electrolyte of weak sulphuric acid; and before describing any special types I will explain simply the chemical changes which the metal and acid undergo during use.

If two clean plates of pure lead are placed in dilute sulphuric acid of about 1·200 specific gravity, no chemical action will take place on either, even if they are joined externally by a wire; for they are in the same chemical condition and sulphuric acid does not attack lead ordinarily. Now pass a current from two primary cells through from one plate to the other, or connect them in series with an incandescent lamp that is lit from a dynamo. After a short time one plate assumes a chocolate colour due to the formation of lead peroxide PbO_2. Then reverse the direction of the charging current by changing over the wires and let it again flow for some time; the chocolate plate gradually assumes a grey tint, while the other plate turns chocolate. The peroxide of lead on the first plate has been reduced chemically to lead again though not in the same mechanical form as originally; it is now in the form of very

finely divided spongy lead, while the other plate has been peroxidized. This combination now constitutes a simple secondary cell, *i.e.*, lead peroxide—sulphuric acid—spongy lead, the peroxide or red plate being the positive pole of the cell, in that a current will flow through the external circuit from it to the spongy lead or grey negative plate. The difference of potential between the plates of a charged cell such as this is about 2 volts. Now if the plates are joined by a wire, a current will flow in accordance with Ohm's law, and will continue to flow so long as the plates retain their difference of potential. When it has ceased both plates will have assumed a uniform grey colour due in each case to the formation of sulphate of lead $PbSO_4$. On again passing a current in the same direction as previously the plates will once more be charged. The reactions in a charged cell when discharging may be written as follows:—

$$PbO_2 + H_2SO_4 + H_2SO_4 + Pb = PbSO_4 + H_2O + H_2O + PbSO_4$$

and to a discharged cell when charging:—

$$PbSO_4 + H_2O + H_2O + PbSO_4 = PbO_2 + H_2SO_4 + H_2SO_4 + Pb$$

i.e., the processes are the exact reverse of one another. During charge the electrolyte is strengthened by the addition of H_2SO_4, whereas during discharge the same amount of acid is taken up by the plates, water being left in its place. This is a most fortunate thing, for it enables the conditions of a cell to be told at once by taking its specific gravity. It would in fact be a perfect guide were it not for one troublesome fact; no matter how carefully the acid is mixed to the required strength, it always happens after a while that the cells differ very considerably from one another, and, furthermore, in any particular cell the electrolyte inevitably has a higher specific gravity at the bottom than at the top.

Another fortunate fact, making these batteries possible, is that lead sulphate is insoluble in the acid. If it dissolved, as does the zinc sulphate in a primary cell, there would be an end to the plate after a few charges. This insolubility also prevents any great amount of 'local action' from taking place on the positive plates; you will understand this by considering a portion of such a plate where we have the backing of unaltered metallic lead, the peroxide upon it, and the acid around. Here are all the elements for chemical action within the single plate, and the peroxide might all be used up in opposing and disintegrating the plate that holds it, but a coating of insoluble sulphate soon protects the metallic lead and stops the process.

Plain lead plates offer so little surface, and therefore support so little active material, that they are no use for practical work, and the batteries now in use shew a number of most ingenious ways by which the surface exposed to the acid can be enormously increased as compared to that in a plain sheet of lead. There are two distinct classes of battery plates; those in which the lead itself is ribbed or made porous by the use of lead wire or ribbon, crystallized lead, or specially rolled plates like a *filmil* (known as the Planté type) and those in which a supporting plate of lead, pure or alloyed, is used as a backing and conductor for a paste of active material, this usually being composed of litharge or red lead (called pasted plates). The competition

between the two classes of plate is strong and healthy, and improvements are constantly effected, but the best types still leave very much to be desired. The troubles that arise are of several sorts, viz., buckling of plates causing short circuit, loss of 'capacity' through flaking off of the active material or the dropping out of pellets, and partial short circuits due to the piling up of the disintegrated material in the cell. So long as the cells are not subject to vibration the plates will last some years, but the trouble is to get plates that will stand the rough usage of a motor- or tram-car. Manufacturers from time to time claim to have solved the difficulty, but only time will decide on the truth of their claims. The chief manufacturers of pasted plates are the Electrical Power Storage Company (E.P.S. type), while the other types are well represented by Tudor, D.P., Chloride and other batteries.

A cell may contain any odd number of plates, 3, 5, 7, &c., but always one more negative than positive, so that the end positives each have a negative plate opposing their outer surfaces. The plates are generally sent out in sections sufficient for making up a cell; thus for an 11-plate cell the five positives will be all burnt on to a common lead bar, the space between them being filled by packing for safe transit, and so also with the six negatives. Each plate is about 1 foot square and ½ inch thick. They will be mounted in a glass cell a few inches larger each way than the plates actually require, and there will be some form of insulating support at the bottom of the cell to relieve the lugs from strain. Glass or vulcanite separators will be fixed between the plates to space them properly, about ¼ inch apart. A plate of glass is generally laid over the top of the cell to keep the acid spray to some extent from diffusing into the air. The positive plates of one cell are joined to the negatives of the next, either by the lead burning process with an air-hydrogen jet, or else by bolting together the two lead lugs. The electrolyte should always cover the plates to a depth of ½ inch or so. Each cell stands on a wooden tray, which is mounted on oil insulators. Metal-work should be avoided as far as possible in the construction of battery stands, and all wood and metal must be thoroughly painted over with a special enamel that resists sulphuric acid. As the weight of a battery is very great, the stands must of course be most solidly constructed, and they should also be so arranged that inspection of the cells is easy

The E.M.F. of a battery depends of course on the number of cells in series, each cell giving 2 volts on discharge. The maximum current depends practically on the number of plates, since the greater the number the lower the internal resistance. But there is a practical limit of discharge rate for each type of plate, beyond which disintegration is unduly hastened. It varies from about 4 ampères per plate for the pasted type to nearly 7 for some of the Planté type. When the discharge is coming to an end, the E.M.F. of the cells drops a little until it gets to about 1·8 volts per cell only, after which no more current should be taken. If this is disregarded, the E.M.F. in a few more minutes drops down to zero, and some of the weaker cells may consequently suffer reversal through being charged by the stronger ones—to their great detriment.

The 'capacity' of a cell, or the number of ampère-hours which it is capable of giving, depends always on the amount of active material, and at each discharge on the rate of that discharge in ampères. Thus, a good pasted-plate type of cell will give from 13 to 16 ampère hours per plate, and a Planté type from 23 to 30. In charging accumulators an E.M.F. of about $2\frac{1}{2}$ volts per cell is necessary towards the completion of the charge, as the back E.M.F. of the cells rises considerably above the normal 2 volts, and the charging current should not be much above half the highest discharge rate. When a cell is fully charged, a quantity of gas is given off—since the plate can utilize no more—and the electrolyte becomes quite milky in appearance. This is therefore another sign that the charge is complete.

If a battery were to be used in our model installation it would be advisable that it should be capable of maintaining all the lights on at once for three or four hours. The capacity must therefore be about 200 ampère hours, and the E.M.F. 113 volts. To obtain the E.M.F. 57 cells are necessary, but we must have at least two more than this, in case any get out of order or lose their capacity. If we take Tudor L-type accumulators as an example, cells of 9 plates will be more than sufficient; for such cells the makers guarantee that the capacity is—

216 ampère hours at 72 ampères discharge,
240 „ „ „ 48 „ „
280 „ „ „ 28 „ „

and 7-plate cells would almost be sufficiently large.

Dynamo for battery charging.—In an installation with batteries the dynamo must be shunt-wound, since a compound-wound machine will be reversed if its E.M.F. drops below that of the battery, whereas a shunt machine merely runs harmlessly as a motor, in the same direction as before. Presuming that the battery will be charged during the day and that the lights will be run from it at night, the dynamo for our installation need not give above 40 ampères. A charge of six or seven hours at this rate will bring the battery fully up again even if totally exhausted. We must allow $2\frac{1}{2}$ volts per cell, or 147 volts for 59 cells, as the E.M.F. of the dynamo. Thus the dynamo output will be 147×40, or 5,880 watts, which, divided by 746, gives 7·9 electrical horse power (E.H.-P.), requiring an engine giving about $8\frac{1}{2}$ I.H.-P. to drive it if it is a small high-speed machine. Regulating gear must be provided to enable the E.M.F. to be gradually raised, since the full 147 volts will only be required at the end of the charge. Of course this can be done by altering the engine speed, but that is an inconvenient method; the usual way is to have a resistance coupled in series with the shunt, and a regulating switch by which more or less of the resistance can be utilized as desired.

The calculation of such a resistance is not a difficult matter, but to bring it home to you I will work out an example which occurred in an actual dynamo of rather smaller size than this. The machine in question was required to give 110 volts and 45 ampères at 1,200 revolutions per minute normally, for running lights in parallel with a battery. But it was also required to give 135 volts for battery charging, when run at a speed of about 1,450

revolutions. Now the E.M.F. is raised exactly in proportion to the speed, other things being unchanged, but as the E.M.F. rises so will the shunt current. Consequently enough resistance had to be added in this case to keep the shunt current constant. The total resistance of the shunt when hot was 40·8 ohms, which at 110 volts gave a shunt current of 2·7 ampères. The total resistance of the shunt and added resistance together, to give this same current at the higher pressure, must be $\frac{135}{2 \cdot 7}$, or 50 ohms. Therefore the added resistance alone, when hot, must be 9·2 ohms, which would mean about 14 ohms cold if platinoid is used; and it must carry 2·7 ampères. The size of wire is determined by the current—a resistance coil of platinoid being worked up to about 2,500 C.D.—and the length of that wire is then calculated to give the right resistance by the formula—

$$\text{Ohms per yard} = \frac{762}{(\text{diam.})^2 \text{ mils}},$$

the diam. being expressed in mils or $\frac{1}{1000}$ths of an inch. The usual method of arranging resistances is to wind the wire in spiral coils and then stretch them between porcelain insulators mounted on an iron frame. Wires are led off to the multiple contact switch from points that divide the resistance up equally. The frame should be fixed in a well ventilated place, since it will get fairly hot, and the cables should be kept quite clear of the hot coils.

Switchboard for battery installation.—The switchboard for use with a battery has to be slightly more complicated than the one previously described, for, in addition to the other gear, an automatic cut-out and battery regulating switch have to be added. Automatic switches for this class of work are often so arranged that the current passes through a lever arm dipping in a metal cup of mercury, which conducts the current on. Should the dynamo E.M.F. at any time fall below that of the battery, a solenoid draws the lever up out of the mercury cup, thus breaking the circuit at the moment when practically no current is passing. The battery regulating switches are of the multiple contact type as shown in figure 51. You will see that if a dynamo

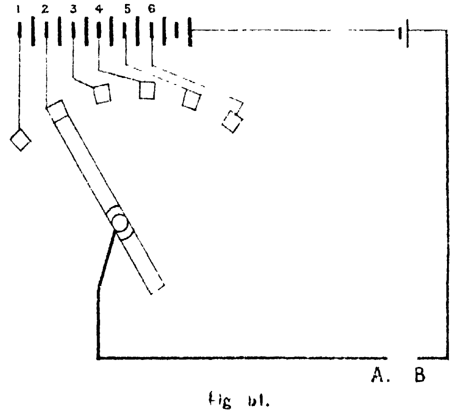


Fig. 51.

is connected across at the points A B the current from it can be passed through either the whole battery, by putting the switch on the end

contact, or through any less number up to the sixth contact. If, again, the lights are connected in parallel to mains issuing from A B, then the E.M.F. can be regulated to the extent of two volts per contact, and the required pressure obtained. These constitute charge and discharge switches. Note that the connecting wires from contacts at 1, 2, &c., must be large enough to carry the highest discharge rate of the battery, since the full E.M.F. will then be employed; the contacts 5, 6 may have smaller connecting wires since the current is there at a minimum. On some battery switch-boards a special switch is also added, by which the ampère meter can be made to read either the current the dynamo is giving, the current the lamps are taking, or the charge or discharge current of the battery.

Maintenance of installation.—We have now completed the survey of the installation under various conditions, and can turn our attention to the maintenance of it in working order. In the house a test should occasionally be made to see that the insulation resistance keeps up. If it is too low take the branch distributing circuits one by one and find out which of them gives a low result, disconnecting each in turn from the rest at the switches or fuses on the main distributing board. Having found the faulty one test each of its lamp circuits in turn, and so gradually localise the fault or weak place.

Occasionally more lights will be required in some room, and here much caution is needed. If the wires are already fully loaded a new circuit must be run from the distributing point, otherwise the lamps already up will not get their proper volts. People are also fond of putting 50 C.P. lamps in pendants intended for 16 C.P., and are then surprised that they look "like red-hot hairpins." Probably the drop in volts is such that they are not giving half their candle-power, while the insulation of the wires is being ruined. If a temporary circuit is run for a special reason see that it does not remain in use indefinitely without being put into proper order. See also that broken or cracked wall plugs, fuse covers, and so forth are not allowed to remain.

In the engine-room see that everything is kept clean, and that faults are put right when first detected instead of when they cause a breakdown. Keep the commutator of the dynamo clean, and the brushes well set; sparking is generally a quite preventible evil.

Turning now to the battery, if it is to last a long time it must above all things be well looked after, and intelligently. During discharge individual cells should be examined to see that they are in working order. When the discharge first begins see that the E.M.F. registered on the voltmeter works out at 2 volts per cell; if less, one cell is probably not in order. As discharge proceeds the volts will drop gradually, but if at any time a sudden drop is noticed try every cell in turn with a 2-volt testing voltmeter. If a cell runs out, short circuit it across with a piece of copper large enough to carry the whole current; otherwise it will pass through the cell and charge it in the wrong direction, since there is no back E.M.F. to resist it. A cell may run out with one set of plates still capable of discharging, if the active material on the other plate is exhausted. To find out which

plates are exhausted, charge up two little plain lead plates such as I first described. Introduce the positive into the electrolyte of the bad cell and test if there is any P.D. between it and the set of negatives; if there is, those plates are good still. Then try the negative test plate across to the positive set, and in that case no P.D. will be found, shewing those plates to be exhausted. See that the electrolyte covers the plates sufficiently and take the specific gravity from time to time, adding water or dilute acid as may be required. I have found the following a useful hint: mark off three or four cells of good capacity and take their specific gravity constantly when fully charged and when discharged, note the mean of the results, and then under ordinary working conditions a few minutes will always suffice to give a very close measure of the amount of charge still left. See also that all connections are kept in proper order and that the acid cannot attack them. Look out for loose pieces of active material and remove them. Keep the trays and insulators clean so that the battery remains well insulated.

Notes on existing installations.—To conclude this survey of private house installations, I will add a few notes on certain existing installations.

In 1898 I was called upon to report on the condition of the installation at Viceregal Lodge, Simla, which had been giving considerable trouble, and I will tell you some of the points noticed. The installation was over 10 years old and was therefore very much out of date in many ways, and it had also suffered considerably from not being sufficiently well looked after. It was in some respects unfortunate that my tests had to be made in December, since in such a dry month there was but little inducement to the faults to shew up, and the measured figures of insulation resistance demonstrated how very little criterion this test was of the real state of affairs.

The first trouble encountered was that due to the inaccessibility of the casing, a point I have spoken to you about. Wherever possible the casing had been run behind carved wainscotting and panelling, or under floors tongued and grooved; or rather, the casing was run first and the other work was afterwards fixed over it. In many cases the floors had to be simply broken open. It is sometimes unavoidable to put casing under floors, but in such cases the planks immediately over the wires should not be interconnected but merely screwed down with brass screws. All the wires were run (nominally) in casing, but in many respects the rules of good wiring were broken, generally during repairs, and not, I believe, by the original contractors. Thus where a Tee joint was taken off (and they were legion) the outer wire touched the other at the crossing; and not infrequently at an awkward point, where extra care should be taken, the two wires were squeezed into one groove together. As these things generally occurred where the insulation was already weakened by a joint, often badly insulated itself, the absurdity of running any of the wires in casing at all became the more apparent.

In one room it was found necessary to pack the interstices of the floor and ceiling with something which would deaden outside sounds; a mixture of sawdust and other ingredients was apparently packed in wet, the conductors being completely surrounded by it! Naturally there was electrolysis at the weak points, which were many. Again, the

casing was in many places sunk flush in the plaster of damp outside walls, with the same result.

Joints, as usual, were the chief source of weakness. Many had been fluxed with sal ammoniac or chloride of zinc, and these had in some cases been eaten right through. Among the recent joints—repairs!—there were some with the wires "merely hooked together, without any pretence at more than the merest contact, and then roughly taped over so that the copper could be seen through the cracks. But few of them were even mechanically sound, hardly any of them soldered." There was also a lot of pseudo-temporary work, and I will again quote from my report ". . . . . in many places I found work originally meant to be only temporary, remaining permanently in use. This took various forms; thus extra fittings have been wanted, such as wall plugs for serving portable lamps, and cables have then been run down the woodwork close together and fixed by metal staples . . . . ." Again, "twin flexible cable of poor quality has in places been imperfectly joined to other cables and run in casing, probably an urgent repair" forgotten promptly. "Bedroom pendants have had to be moved a few feet away from their ceiling roses; staples have then been used as a means of fixing the flexible." I need not comment on these examples.

Another grave feature was the constant use of 16 or higher C.-P. lamps where 8 C.-P. was intended. So far as the lamp load itself is concerned this may not matter generally, but it does matter to the sub-mains. The latter are apt to be calculated for the current required for the original lamps; if the C.-P. is doubled throughout the lead has 100 per cent. overload, and I found one case of 200 per cent. overload. Even the flexibles of pendants are liable to be damaged when 50 C.-P. lamps are put on to a 35/40 as in another case. Apart from the damage to insulation and possible fire risk, the inevitable result of these doings is a large drop in volts in the leads and consequent loss of light. The same thing will result if extra circuits are run from fully loaded distributing boards. I have guarded against trouble from these causes at Government House, Calcutta, by two useful precautions, which, however, on account of expense would often not be admissible—first, by calculating the current in every case on the assumption that every lamp will be of at least 16 C.-P. and will take 3½ watts per candle, whatever the immediate intention actually is with regard to it; secondly, by having all mains and sub-mains of such section as to give 500 C. D. only in the first instance, so as to give ample margin for the extensions inseparable from a large installation with fresh tenants from time to time.

If an installation has to be examined after a good many years it generally happens that no one knows where the wires run to or what circuits the cut-outs control. To obviate this it is useful to insist that "after the contract is completed the contractors shall supply accurate and easily understood wiring plans of the whole installation, showing distinctly the course and size of every wire in the buildings, with the position of every lamp fuse, switch, &c., and the maximum current which every fuse is liable to carry." Also that the distributing boards should have all their fuses labelled "with a reference number or letter, by means of which the circuits they control can easily be found on the wiring plan."*

* *Vide* Appendix V, Form of wiring specification.

LECTURE V.

Central Station Supply.

THE distribution of electricity from central stations is a subject which might easily take up several of these lectures if treated fully, but I shall confine myself to-day chiefly to the consideration of what appears most likely to be of practical use to you here. Such distribution may be by means of either continuous or alternating current, each having the advantage under certain conditions, and we will consider them in turn.

In the last lecture we discussed the details of a simple continuous current installation at a pressure of 110 volts. With larger plant and bigger mains the same system would have served a number of houses equally well, and this 2-wire continuous current system with batteries is about the simplest form of distribution from a central station. It is, however, seldom adopted, since considerable economy can be effected by the use of the 3-wire system, which I will now proceed to explain.

Three-wire system.—Suppose we have a battery of 110 cells, the P.D. between the terminal point will be 220 volts, and the P.D. between either end and the middle point of the whole battery will evidently be 110-volts. From these three points take three conductors, which we will call the positive and negative 'outer' conductors, and the 'third wire' or neutral middle conductor. Evidently with this arrangement we can put 110 volt lamps in parallel between either outer wire and the third wire and they will light up. Or on the other hand we can simultaneously put lamps time in parallel between both outers and the third wire, and both sets will light up independently. In the diagram

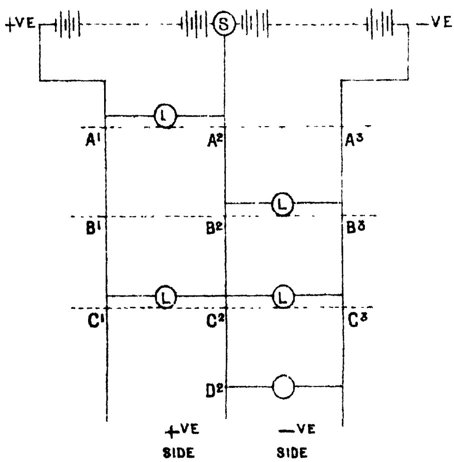


Fig. 52.

(Fig. 52) I have shown this arrangement, and I wish you to suppose each of the circles L to represent an installation of (say) 20 lamps in a small house, of which five are for example shown, two on

the positive side of the neutral wire and three on the negative side. At the point S a switch is inserted in the third wire for explanatory purposes, though such a switch would not be at all advisable in practice as you will presently see. Across the three conductors I have drawn dotted lines $A^1\ A^2\ A^3$, $B^1\ B^2\ B^3$, etc., just beyond the points where each set of lamps are taken off.

First of all consider the system to end entirely at $A^1\ A^2\ A^3$; there is one batch of 20 lamps, say 12 ampères, on the + side and nothing on the other, so 12 ampères will flow from the + pole of the battery through the lamps to the third wire, and thus back to the centre point of the battery. This then becomes the negative pole of the half battery supplying the current, and the other half battery is entirely idle and on open circuit. Open the switch S, and the lamp circuit is broken, so both halves will be idle.

Next close S again and take the system up to the points $B^1\ B^2\ B^3$; that is to say, with 12 ampères on each side of the neutral wire. Assuming for the moment that each 12 ampères are independent of the other altogether, the original current will behave as before, while the new 12 ampères will start from the positive pole of the second half battery (that is, from the third wire terminal), and go through the lamps to the outer negative terminal. Now considering the two currents together, we find that we have two 12 ampères apparently flowing in opposite directions in the third wire. Actually, therefore, no current at all flows in it, but the current instead passes from the positive pole of the whole battery through the two installations in series to the negative pole of the whole battery, with the full 220 volts to overcome the double resistance. Open the switch S, and it makes no difference whatever to the light. But note that the second 12 ampères *do* flow in part of the third wire, namely, from B^2 to A^2.

Take the system up to the points $C^1\ C^2\ C^3$ now, thus adding 12 ampères more to each side of the system and making 24 ampères in all on each side. As before no current flows past the switch S, since we have 220 volts causing a current of 24 ampères to flow through two batches in series, each of 40 110-volt lamps. As before 12 ampères will be flowing from B^2 to A^2, but since the two new and equal installations have been coupled on to the same point on the third wire, no current will flow from C^2 to B^2.

Finally, add 12 ampères more on to the negative side only, beyond all the rest. This side is now 'out of balance' with the other, having 36 ampères against 24. The difference will have to pass through the whole length of the third wire, and the negative half of the battery will have to give 12 ampères more than the positive half. The piece of third wire from B^2 to A^2 will have 24 ampères in it, since it previously had 12 ampères flowing in it in the same direction. If now the switch S is opened there is a serious upset of the arrangements, for we shall then have a pressure of 220 volts applied at the ends of two unequal resistances in series. The current is of course dependant on the combined or added resistance, and the same current must flow through both sets of lamps, first dividing itself up among 40 and then among 60. Evidently each of the 60 lamps will get too little current and give a dim light, while each of the 40 will get too much and be

disintegrated by the excessive temperature of its filament. Thus you will see that, with a three-wire system, the middle wire carries no current so long as there is a true balance between the sides, and under other circumstances it only carries the difference between the current on the two sides; it can therefore be made far smaller than the two outer conductors (usually half their area) and a large saving of copper is effected.

The battery of course needs charging, and a dynamo giving an E.M.F. of $110 \times 2\frac{1}{2}$ or 275 volts will do this; but such a dynamo will charge the whole battery alike, and will therefore be unsuitable if half the battery needs more charging than the other half, as will be the case if the lamps have been out of balance during discharge. It is also necessary, therefore, to have a smaller dynamo giving about 138 volts and capable of being connected to either half of the battery as need arises as shewn in Figure 53.

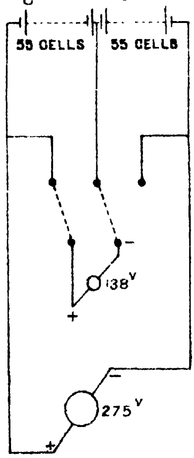


Fig. 53.

If the mains on such a system as this are of considerable length, it will be necessary to make them very large in order to keep the E.M.F. practically the same at all points, and, to get over this difficulty, the same device is adopted that I have already described in connection with internal house wiring. 'Feeder' mains are taken from the station to various convenient centres of distribution, a certain predetermined drop in pressure being allowed and compensated for at the station. No lamps are lit off these mains; they simply act as feeders or suppliers of current to a net-work of distributing wires. The latter are made large enough to carry their maximum current with very little drop in pressure, so that all consumers get nearly the correct E.M.F. The feeders have two large 'outers' and a 'third wire' of about half the sectional area, while from each feeding point a 2-wire net-work runs in every direction, consisting in each case of one outer and the neutral wire, and both of equal size; from this branches are taken off to each installation as required. In very populous localities the net-work will also have all three wires, houses being alternately connected to either side.

In all cases, the total number of lights connected on the positive side should, as far as possible, be equal to the total number on the negative side, both in individual streets and in the aggregate, so as to reduce the current in the third wire of the feeders and keep the batteries discharging equally. Even a large battery would be unable to supply power to a town for long, so in practice the dynamos are run in parallel with it; the former then serves to take up any sudden load that may be thrown on, gives more current on either side that requires it if the balance is bad, takes up the small load from midnight onwards, and saves the cost of extra dynamo and engine-power for tiding over the short time when the load daily rises to a maximum, generally just about the hour of late dinner. I shall show you some diagrams later on (*vide* Figure 75), from which you will see that the last function of the battery is most important, since the peak of the load curve is most pronounced.

I now shew you a diagram giving the connections of a central station switch-board for a three-wire system with batteries, opened out in the clearest way for the avoidance of crossing lines (Plate I), and for reference I also give a diagram of the gear as actually arranged on the switch-board (Plate II).

During the last few years most electric supply stations have been designed for 220 volts at the lamps, so that there is a pressure of 440 volts between the outers of a three-wire system. To the consumer this makes comparatively little difference, though he has to pay rather more both for lamp renewal and current, but to the supplying party it makes a great deal. To supply a given number of lamps at double the pressure only half the copper is necessary in the mains, and the area that can be economically served from the station is increased four-fold, so that far more consumers can be obtained. Calcutta is served on this system, and I shall presently give you some particulars of the scheme.

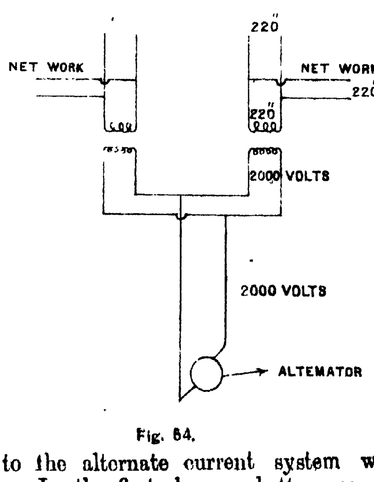


Fig. 64.

Turning now to the alternate current system we have quite different conditions. In the first place no battery can be used, since

an alternating current is useless for charging purposes—each reversal would neutralize the chemical effect of the preceding half cycle—and consequently the regulation will be entirely through the engine or dynamo. The usual system is to generate current at high pressure, 2,000 volts or upwards, carry it to convenient centres of distribution, and then transform it down to the working pressure of 220 or 110 volts for use, distributing it by a network as in the previous instance (Fig. 54). I shall, in my last lecture, describe such a system to you, confining myself now to a few general remarks. If a given number of horse-power are to be transmitted from a central station to a certain point or distributing centre, the higher the E.M.F. is the smaller will the current be, and the smaller also the conductor for carrying it. Where the distance is great this makes a great difference in the cost of a scheme, so in such cases alternating current is usually adopted. Of course continuous current can also be generated and transmitted at high pressure, but it does not offer such facilities in the way of transformation to lower pressure for lighting work. If a continuous current is available at 1,500 volts and we want to light 110 volt-lamps with it, we must use a motor-generator to effect the transformation, supplying the motor at 1,500 volts, which in its turn drives a 110-volt dynamo. In the case of alternate current we need have no moving machinery at all to do this, which is a great consideration.

Mains.—I have already briefly described two methods of running mains in discussing private installations, and I will now go rather more fully into these and other systems.

Overhead mains may be either of bare copper or insulated cable. In England the use of bare copper is in general prohibited, but in India I consider it to have great advantages over the other method for most purposes, since insulation exposed to the weather inevitably perishes after a few years and thus becomes a source of false security, while a bare wire carries its character on its face. For a system of bare overhead mains it is usual to use solid hard-drawn copper wire. The resistance of this is a trifle greater than that of soft annealed copper, such as is found in cables, but the strength is very much greater, and if soft wire were to be used there would be a danger of it being actually stretched during straining up which would reduce the cross-section and increase the resistance of the conductors. Poles may be of almost any construction that is used for telegraph or telephone work, provided that they are strong enough and tall enough to fulfil the conditions of the Government regulations.* Insulators may also be similar to those used by the Telegraph Department, shackle insulators being used where there is danger of bending the stems of ordinary brackets. In erecting small gauge wire care must be taken to avoid letting it touch the ground, since even scratches render the wire liable to break later on. Kinks of course need careful treatment in all cases, and if they have by mischance been pulled up tight it is better to cut the bad piece out and make a joint. The Telegraph Department form of joint ("Britannia joint") is best for this class of

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* "Rules passed under Section 4 of Act XIII of 1887," Government of India.
"Calcutta Electric Lighting Regulations," passed under Act IX of 1895, Government of Bengal.

work; clean and lay the two wires alongside for a few inches, according to the diameter of the wire, turning the ends up very slightly, then

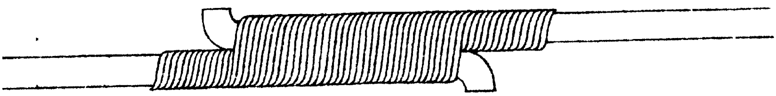


Fig. 55.

bind the overlap with a smaller size binding wire, giving the two ends of the binder a few turns beyond the joint, and solder thoroughly (Fig. 55). The soldering should also be done quickly, as the temper of the wire is liable to be lost if it is overheated. In straining up the wires the custom here is to use a block and tackle, gripping the wire with a few turns of 3-ply rope instead of using a vice. Spans should range from 150 to 200 feet, and in every case where a street is crossed a pole must be placed on each side of it, under the Regulations. Where the line makes an angle the pole must be stayed either with one stay at the resultant angle of the strains or with two in the two alignments, according to whether the angle is small or large. In the case of small angles the brackets may be so placed as to bisect the angle, but where the wires turn a right angle it is best to terminate them at an insulator in the alignment, and then start afresh with a new line, connecting the two together by a short length of the same wire. Terminal posts must of course be stayed, and in a long straight line of poles it is advisable to stay the ends of any specially long span, so that the breaking of a wire may not cause a number of poles to fall over. If a long line is exposed to the force of the wind, side stays must occasionally be fixed also. Stranded galvanised iron wire is the best material for stays, and a big stone buried fairly deep down acts as an excellent anchor; screws for altering the strain are generally fitted also. It is generally better not to run the wires in pairs on double brackets, as they may blow together in a wind; single brackets a foot or so apart, on opposite sides, prevent this and make an equally neat job. On the three-wire system the third wire can be conveniently put over the top of the pole. Where the line is a high tension one oil insulators are generally used, but such a line of uninsulated copper would not be permissible except for transmitting power cross-country.

In England overhead wires are bound by regulation to be insulated and suspended from a bearer wire, except in the case of the 'trolley wire' of a tramway; indeed they are very seldom allowed at all there, as the necessity does not exist to the same extent as in India. Here they are, or are being, erected in various places, with the express consent of Government in each case, and there is little doubt that they offer the greatest advantages of any system having regard to the peculiarities of the climate. Any high-pressure line in a town would, however, be insulated, and we have an example of this in the Harrison Road arc lighting, where the maximum E.M.F. is about 1,400 volts. The rule for the radial thickness of the dielectric (or insulating material) for high tension lines is that it must "not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts

by 20,000, with a minimum of one-tenth inch."* There is a bearer wire of 3/16 galvanised steel run on insulators, and the cable is hung from this by raw-hide suspenders, so that no strain comes on the wire or its covering. Strictly speaking, the cable should be at a height of 18 feet ordinarily and 30 feet where it crosses a street, but this rule, being of later date than the installation, was not afterwards enforced in this particular instance.

Underground mains, bare.—Coming now to underground mains we can again use either bare or insulated copper. It was originally proposed to use bare underground mains in some parts of Calcutta, but the idea was wisely given up, partly owing to the difficulty of preventing water from accumulating in the conduits. In the Crompton system of bare underground mains a concrete conduit is built, with manholes at fairly short intervals. At each manhole there are supporting insulators, and the conductors on these consist of copper strips 1 inch wide and $\frac{1}{8}$ or $\frac{1}{4}$ of an inch thick, which at the end of a straight run, and at intervals everywhere, are strained up tightly. This system can be most easily applied in places where there are long straight runs and enough slope to make the drainage of the conduit easy; it has the great advantage that everything is open to inspection and easy to repair, and that if a conductor becomes overloaded as time goes on, another pair of strips can easily be drawn in and fixed over the existing ones. Joints for house services, &c., are made with gun-metal clips, insulated wires being taken into the houses in iron pipes. Where the conductors cross under a road, a short length of multiple way iron pipe is laid and insulated cable is drawn through.

Underground insulated mains.—I have already mentioned the advantages of running cables in bitumen, and this is done in the "Callendar" system, of which there are many miles under the footpaths in Calcutta. A cast-iron trough of rectangular section is laid in a trench, successive 6-foot lengths being bolted together; into this wooden bridges are placed at short intervals, each with as many grooves spaced out as are needed for the cables. The conductors are insulated with prepared tape, apparently soaked in bitumen (the actual material and process is a patent), and they are laid along the bridges in the trough. A small amount of melted bitumen is then poured over all the joints of the troughing and over each wooden bridge, and when this has somewhat set, the whole trough is filled in entirely with that substance. Before it has set a cast-iron cover in 6-foot lengths (usually broken into shorter lengths still on the spot) is pressed on the top, the joints in the cover being further protected by an extra layer of bitumen outside. Joints in the cable are made by the use of metal sleeves fitted over the strands and then filled in with solder, and the special insulating compound is used around joints in place of simple bitumen.

In all the various systems of mains laying, the feeders and network can of course be run in some places on one set of poles, or in

* "Where the conditions of the supply are such that the pressure may at any time exceed 500 volts if continuous or 250 volts if alternating, but cannot exceed 3,000 volts, whether continuous or alternating, the supply shall be deemed a high pressure supply." (Calcutta Electric Lighting Regulations.)

one conduit or trough, and a saving in both labour and material is effected. Where, however, the system is alternating with transformers, the high and low pressure conductors should always be kept quite out of each other's way. Before leaving this branch of the subject, I may just mention one or two other systems of carrying conductors underground; the cables may be lead-sheathed and armoured with steel wires and buried direct in the ground; they may be run in stoneware conduits (Doulton system) or in iron pipes; or they may be run in pipes filled with an insulating oil as in Johnson and Phillips' system.

Regulating gear.—In a large central station many dynamos will have to be running together in parallel with one another—and with the battery where there is one. The governors on the modern high speed engines that do this class of work will regulate to within about $2\frac{1}{2}$ °/$_o$ under all ordinary changes of load, so as a rule the stop valves are opened wide, and the regulation is in direct current installations, entirely done by altering the shunt resistance. This should be such that the load can be altered by it from full to light in gentle steps. When a dynamo is to be put on to the circuit, it is always a good thing to first try that the governor is in proper working order, by running up to full speed and then pulling down the rod through which the governor acts on its throttle valve; this should cut off the steam at once if everything is in order. Before the dynamo is actually switched on, it is necessary to see that its E. M. F. on open circuit, *i.e.*, excited only, is the same as that of the other dynamos, and of course in the case of a new dynamo it is necessary also to make sure the poles are right. In a central station the best way to do this is by exciting the shunt back from the mains with the brushes up; this ensures the correct polarity without any testing or altering of leads. While on this point I may with advantage follow it up a little further.

In starting up a new dynamo in a private installation it may sometimes happen that it will not work, and there may be a number of reasons for this. The simplest of these is that the brushes have not been put down, and I have heard of a man being sent from one end of England to the other to discover no worse fault than this! But assuming that the connections are all in correct order and the brushes down, it still does not follow that the machine will excite. In such cases, you should first try the effect of altering the position of the brushes from vertical to horizontal or *vice versâ*. If that does not put it right, it generally means that the dynamo has not sufficient residual magnetism to enable it to build up a field, since that which it had when tested by the manufacturer may have been knocked out during transit by the jars it has received. Try running up the speed above normal as high as you safely can do it; that sometimes puts it right. If the machine is compound-wound, it can almost always be made to excite by taking a short length of wire and momentarily short-circuiting the terminals, since any current so generated passes through the main coils. Failing all other things it becomes necessary to obtain a few primary cells and separately excite the shunt to a slight extent, and a few blows on the iron with a heavy piece of wood will help the process. On one occasion about three years ago I had to borro wcells from the nearest Telegraph office for this purpose.

Alternators must be of almost exactly the same design to run in parallel, since they must run in exact synchronism ; that is to say, they must be in step, so as to arrive at the maximum E.M.F. at the same instant, and the shape of their curves of current and E.M.F. must be as nearly as possible alike. Once properly in step they will keep each other steady, and it is only necessary to divide up the load evenly between them at the engines. The regulation of E.M.F. is effected in two ways—either by altering the resistance in series with the exciting current and thus raising or lowering it, or by varying the resistance in series with the shunt coils of the exciter, which thus generates more or less ampères.

Time will not admit of more than a passing reference to the boiler house arrangement of central stations. Either Babcock and Wilcox water-tube boilers or Lancashire boilers are generally used, the chief characteristic of the former being quick steaming and of the latter large reserve power. Considerable saving in fuel is effected by the use of feed-water heaters and economisers, and superheating of the steam is also resorted to in many stations. Pumps, blowers and other auxiliary machines are generally run by electric motors now, and considerable economy thus effected over the older method of having numerous inefficient engines and straggling lines of small steam pipes in every corner.

A central station switch-board for a large three-wire system with batteries looks somewhat complicated in front, and still worse among the cables behind, but a fairly simple diagram of the connections can generally be made, as shown in an example just now (Plates I, II). Each pair of dynamo leads is brought to a fusible cut-out in the first place, the current is then taken through the coil of an automatic cut-out, which also acts as a main switch, then through an ampère meter and generally an energy meter as well, and so to the main bus bars; in the case of balancing dynamos there is also a change-over switch, so that it may be put on either side of the system. The construction of one

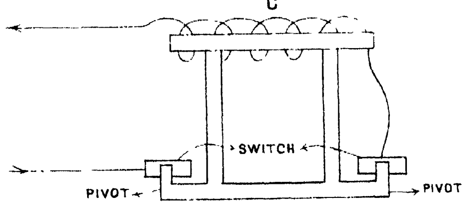


Fig. 56.

reliable type of automatic cut-out is shown diagramatically in figure 56. A solenoid carries the whole current, and magnetically holds up an iron frame working on a hinge below. After passing through the coil the current is led to a terminal A, from which it has to go through a switch to get to the terminal B. If there is not sufficient current to hold up the frame work it falls by gravity, and a ratchet catches the switch and breaks the circuit. If therefore the dynamo E.M.F. for any reason falls below that of the battery, it is prevented from 'motoring' by the automatic cut-out. A 3-wire change-over switch is shown diagrammatically in figure 57.

Leaving the dynamo current at the bus bars let us now turn to the battery. From the middle point of this the third wire is taken off direct to the third wire bus bars on the switch-board, while the regulation is entirely effected by manipulating the cells at either end. Taking one half battery, a certain number of 'regulating cells' are numbered off; all in fact above the number required to give the standard E.M.F. of the station—*i.e.*, 55 for 110-volt stations. From each regulating cell a conductor is taken away to the switch-board, and there they are connected to the terminals of a multiple contact switch, and by means of a lever or handle any number of cells that may be required can be thus connected to the bus bar on that side of the system to which that

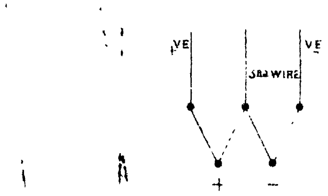


Fig. 57.

battery belongs. Each cell adds two volts, and as the drop in volts in the feeders increases with the current, so does the switch-board attendant compensate for that drop by adding cells, thus maintaining an even pressure in the network. The battery current is measured by an ampère meter on each side of the system, and generally also passes through a meter which registers the difference between the charge and discharge during any given period. Of course the battery needs charging up every day, and this is usually done in the afternoon before the heavy load comes on, but when at any time the external load is suddenly reduced the battery starts being charged. The meter takes account of all these charges and enables the engineer to tell just how much surplus charge is required; it generally amounts to about 15 per cent. over the previous discharge.

From the bus bars of the switch-board the current is taken off to the various feeders, generally first passing through a cut-out on each pole and an ampère meter. So far I have not mentioned the volt-meters; each dynamo has one connected across its main fuses on the board, so have the batteries, and there is also a circuit volt-meter showing the pressure on the network, which must be kept up to standard. The wires for this are sometimes connected to the net-work where it passes the works, but the best way is to carry out three small "pilot wires" to a feeding point and connect them there to the two sides of the system.

Instruments.—I shall only say a few words about instruments. Volt-meters may be either electrostatic or electro-magnetic, the latter having coils of very high resistance, so that the power they waste is very small, while the former of course waste no power at all: or they may be constructed on the Cardew principle of measuring the quantity by the alteration of length of a wire when heated by a current. Ampère-meters, having usually to carry the whole current, are of very low resistance, thus reducing the loss of pressure over

them to a minimum, and consequently the loss of power. Lately shunted ampère meters have been introduced, wherein only a certain definite proportion of the total current passes through the instrument, and also hot wire ampère-meters, acting as described above for volt-meters.

For measuring energy there are a number of types of meters; some actually integrate the volts and ampère-hours, while others measure the ampère-hours actually, but, presuming the standard E.M.F. for which the meter is calibrated, read in B.O.T. units. The Aron meter has two pendulums worked by electrically wound clockwork and connected to a set of dials through differential gearing. Both pendulums carry electro-magnets, wound in series with one another and in shunt to the circuit, and they swing over two coils, also in series, carrying the main current. The connections are such that while one pendulum is accelerated the other is retarded, and the gear registers the difference between the two and records in Board of Trade units. Every half minute the direction of the current in the pendulums, and the direction in which the gear is driven, are reversed, thus rendering exact synchrony unnecessary. It is suitable both for direct and alternating current. In the Ferranti direct current ampère-hour meter the current has to pass through a trough of mercury placed between the poles of a magnet, and the consequent rotation of the mercury, which is proportional to the current, is communicated to the train of wheels.

For measuring alternating currents the Shallenberger ampère-hour meter is very generally used. In this meter the train of gearing is actuated by the rotation of a small disk of metal placed in the combined field produced by two coils mounted in different planes. One coil is connected in series with the circuit to be measured, and the other is a closed coil in which a current is induced by the former. The two fields are continually varying asynchronously, and the revolution of the resultant field causes the disk to rotate. Vanes are fitted as a drag and are regulated until the meter reads correctly.

Lightning arresters.—Over-head wires have to be protected by lightning arresters; the simplest and probably the best for low tension work is shown in the diagram (Fig. 57). Two diverging arms of

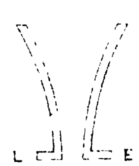


Fig. 58.

copper are mounted on insulators, one connected to the 'line' and the other to 'earth.' At the lowest point the arms come to within about $\frac{1}{8}$ inch of one another, thus offering a very small air-gap and a very easy path for the lightning to bridge. If, however, the dynamo current follows the spark and tries to set up an arc, the heated air drives the arc up the rods until the E. M. F. can no longer maintain it over such a distance. In another well-known pattern the path of the lightning to earth is through a long

pivoted lever arm and a carbon contact to another contact connected with earth. If the dynamo current follows this path it has to traverse a solenoid, which pulls the lever away from the earth terminal and breaks the arc. Other types will be described later on.

The shunt resistances that regulate the dynamos are not placed actually on the switch-board, though capable of being worked from the same platform. They give off considerable heat, and are therefore more conveniently fixed on a wall where they can cause neither damage nor discomfort to the attendants. A switch-board for alternate current work is much simplified through the absence of battery arrangements. Switches and cut-outs for high-tension currents are of quite different construction to those previously described, since an E.M.F. of 2,000 volts (say) could maintain an arc between the terminals of low-tension gear. Main fuses are generally a foot or more in length, one type being contained in glass tubes mounted on an ebonite frame, which is put in series with the circuit by means of two pins or plugs. Plugs are also often substituted for switches, the detaching of a framework opening up the circuit simultaneously at two places on each pole.

Potentiometer.—I shall now leave this matter to consider meter-testing for a time, first of all discussing some points about the potentiometer. In works tests of all sorts the potentiometer is an invaluable apparatus, since a number of readings of various quantities of widely different magnitude can be taken in rapid succession and with great exactness. The instrument in its present form is due very largely to Mr. Crompton, and in his Company's works, where I received my practical training, nearly all the work of the testing rooms is done by its use. Since you have a potentiometer in your laboratory, it is to be presumed that you are familiar with the method of working it, but a few remarks on its principles and possibilities may not be out of place (see also Appendix 4).

If an E.M.F. is applied to the ends of a wire in series with a galvanometer a deflection will take place, but if another E.M.F. exactly equal and opposite to the first is also applied at the same points, then the instrument will go back to zero. In the potentiometer we have a wire stretched over a scale with a certain known gradient of potential difference along it. If now we have an unknown E.M.F. between two ends of a conductor with a galvanometer connected in series, and we find two points on our calibrated wire such that the P.D. when opposed to the unknown one causes no deflection, then those E.M.F's. are equal. In the actual apparatus the stretched wire is arranged to have a P.D. between its ends of $\frac{1}{10}$th volt, and each of the 1,000 divisions of it have therefore $\frac{1}{10,000}$th volt drop. There is a multiple-way switch by means of which, when comparing E.M.F's., any required number of extra coils can be brought into the comparison circuit, each one having also a P.D. of $\frac{1}{10}$th volt and being in series with the stretched wire. The exact gradient of potential is maintained by means of one or two secondary cells, adjusted by a resistance and compared first with a Clark's standard cell.

If the E. M.F. to be measured exceed that over the potentiometer coils a "volt-box" must be used. This consists of a specially wound resistance coil such that the highest E.M.F. to be measured can be

connected across its terminals, while other terminals are connected in such a way that there is an E.M.F. of $\frac{1}{10}$th, $\frac{1}{100}$th or any other submultiple of the total between them. The smaller quantity is measured direct, and gives the larger by merely moving the decimal place.

The measurement of current by potentiometer is an application of Ohm's law, for the current is passed through a known resistance and the E.M.F. measured over its ends; if the resistances are decimal fractions of an ohm (as they generally are) the measured E.M.F. gives the figure of the ampères, and only the decimal point has to be altered. Standard resistances are made of 1·, ·1, ·01, ·001 ohms, according to the current they have to carry, in order to give in each case a fall of potential directly measurable. The material they are generally constructed of is manganin (copper 84 parts, manganese 12 parts, nickel 4 parts), since its specific resistance varies to an extremely small degree with alterations of temperature. For carrying very large currents they are for lightness made in the form of thin tube, a constant current of cold water being kept running through and preventing a large rise of temperature, despite the high current density.

The measurement of resistance by potentiometer is simply a combination of these last two methods, since, if a measured current is passed through the unknown resistance and the P. D. is also measured, the ohms are at once given. Of course in all these measures the accuracy of the standards represents the accuracy of the measures, and with poor standards it would be useless to measure to 5 places of decimals. I say this advisedly because it is not unusual for elaborate calculations to be made with apparatus whose accuracy is restricted to two consequent figures, the result being given to 4 figures, and an average being afterwards struck that brings it up to 5 or 6. As a rule, nearly all calculations in electrical works are made on the Gravêt slide-rule, which will give a result accurate to about 1 in 500. It is very seldom that greater accuracy than this is required, and I have worked out most of the examples I have given you in this way.

To mention some daily use of the potentiometer in a works test-room, there will be the following:—Measurement of the resistance of magnet coils directly after—or occasionally during—winding; measurement of the E.M.F. and current of dynamos under test, under various loads and conditions; measurement of the resistance of the armature when cold at the start, and when hot at the finish of the test, and the same for the magnets coils; measurement of current for calibration of ampère-meters or E.M.F. for voltmeters. Another operation for which it is found of great value is cell testing during a rapid test discharge of a battery. To go round 55 cells with a portable voltmeter takes some time, but to run round them with a couple of spiked terminals and see on the galvanometer that all are approximately at the right E.M.F. is the work of a few moments only, provided the man at the instrument end is in good practice and has a quick eye.

Meter-testing.—In a central station the chief uses of the potentiometer are the checking of instruments and measurements during meter tests; and on the latter subject I may be able to give you some useful hints. In testing a meter, current is passed through it for a

given time at rates of full load, half load, quarter load, and at very small values, while at each load the recorded quantities are compared with those actually passed through. Some meters are 'direct reading' in units or in ampère-hours, and should therefore not be passed unless they register correctly within a small percentage; others are 'constant' meters, the recorded figures having to be multiplied by a constant to give the true value, and in these the maker's constant must be checked and (if necessary) altered. Again, some meters actually measure the B.O.T. units by integrating the volts and ampères, while others measure ampère-hours and have their recording gear arranged to read units at the standard pressure of any given installation, which must be assumed correct. To make a test the gear required consists of a battery or other source of power, an arrangement of resistance coils to vary and adjust the current, and a means of measuring the current and the time. I cannot do better than give you an actual test from my note-books, since some of the arrangements were made up on the spot with what apparatus came ready to hand.

I will take as my example the test of a 10-ampère Chamberlain and Hookham direct reading meter (these meters have been considerably altered and improved since the test in question, which was taken at the works of the Hove Electric Lighting Company in 1895). The diagram (Fig. 59) shews the general arrangement for the test; 4 secondary cells—the top or regulating cells of one of the large batteries—were used for giving the current. As this meter was an ampère-hour meter, calibrated to read B.O.T. units when supplied with current at 110 volts, it would have been wasteful to use the whole battery for the purpose, since the resistance of the cells is very low, and by using a few cells only the necessary current could be obtained with very little waste of power. Meters which actually measure the units have a shunt coil which needs excitation at the full pressure; such meters when in use in a house are therefore always consuming a small amount of power even if every light is off, and in installations of one or two lamps the power wasted by the shunt may be more than all that is used by the consumer.

For measuring the current the potentiometer was used, and a 'standard resistance' was therefore coupled in the circuit, and supposing this to have been a $\frac{1}{10}$th ohm, a current of 10 ampères would give us one volt fall to measure. Several meters M.M. were in the circuit for simultaneous testing; for regulating the current a resistance frame with a 6-contact switch R_2 was available, and you will see that a switch S_2 was coupled in such a way as to divide the first coil of the resistance into two parts for convenience. This frame, while giving an approximate current, was not sufficient to adjust the value to just what was required, so the arrangement marked R_1 was made up; it is one of many devices by which a fair range of resistance may be easily and cheaply obtained. The circuit was broken and the ends were connected to two separate lengths of platinoid wire; two screw terminals were threaded on each and cross-connected by thick flexible wire. If now all 4 terminals are carried up to the far end of the platinoid wires they are put in series, whereas if one terminal is at each end of each wire the two are put in parallel, or, again, any part of one wire alone can be used; by intermediate arrangements a very

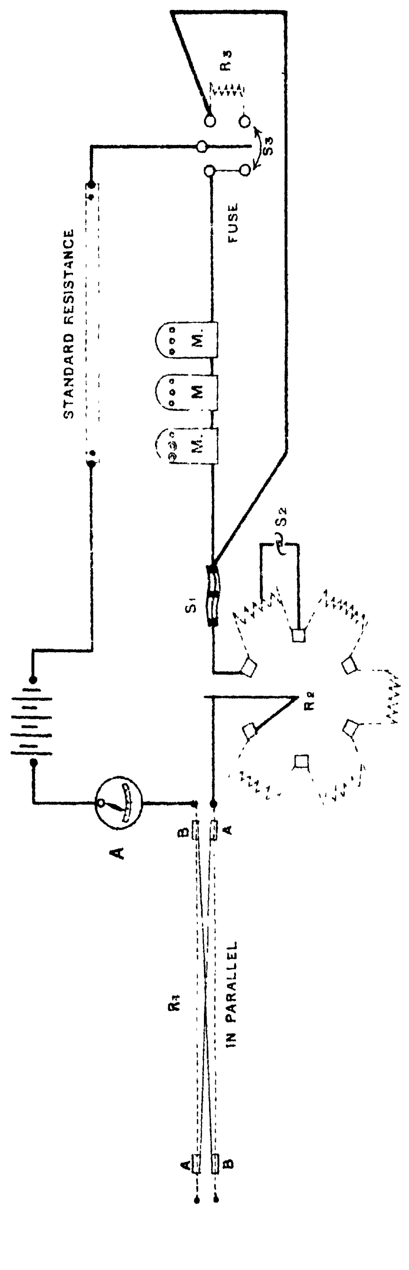


Diagram of meter testing circuit.

Fig. 59.

exact regulation can be obtained. There was also a main switch S_1, and an ampère meter A for rough indications.

The only other gear is the two-way switch S_3 and the resistance R_3; this resistance was approximately equal to that of the meters, and the switch would admit of the current being passed at will through either the meters or the resistance. The reason for having this was that the current could be run through the circuit for a time and adjusted when all the parts were at their proper temperature; then, while the meters were being read before beginning the test, the current was diverted by S_3, which prevented the regulating resistances from cooling down and altering the current. During the shorter tests the current was read on the potentiometer every 5 minutes, in other cases every ¼ hour.

For the tests with very low current the meters move so slowly that they have to be left on circuit for hours. It is therefore generally more convenient in such cases to couple them in series with a lamp on the full circuit, and in the ·9 and ·36 ampère tests below this was done with a 25-C.-P. and 8-C.-P. lamp respectively.

The results of the tests are tabulated below, and I also append a

Duration of each test.	Meter Readings— At start.	Meter Readings— At finish.	Difference or recorded units.	Current, mean of all readings	Actual units.	Constant by test	Maker's constant	Remarks.
4 hours ...	16·325	20·810	4·485	10·100	4·414	·99	1·00	Full load.
2 ,, ...	20·810	22·515	1·705	7·664	1·686	·99	...	¾ ,,
4 ,, ...	22·925	24·955	2·030	4·668	2·054	1·01	1·01	½ ,,
16 ,, ..	24·955	29·470	4·515	2·610	4·590	1·01		¼ ,,
13½ ,, ..	13·800	15·060	1·260	·890	1·322	1·05	·985	One 25-C.-P. lamp.
11½ ,, ...	22·515	22·925	·41	·357	·452	1·10	.	,, 8-C.-P. ,,

curve (Fig. 60) showing the results graphically. It will be seen that the

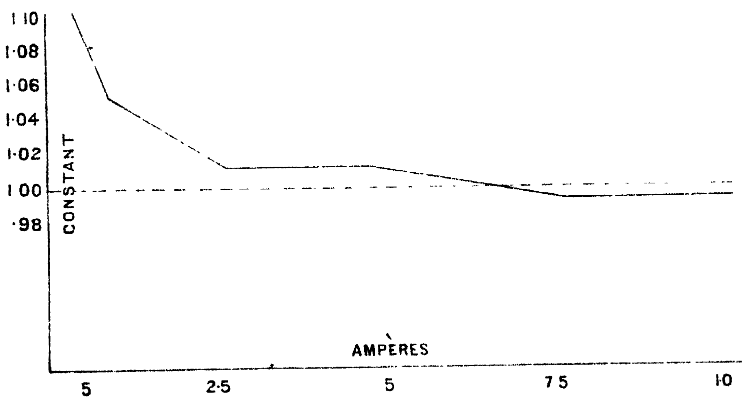


Fig. 60.

result was excellent, and that the registration was very nearly correct except under very small load indeed, where slight inaccuracy costs very little to the losing party.

A test of some meters including the above type may be made by a much simpler method than the one just described, though I am inclined to think it would not generally be accepted as so conclusive by

the consumer. The train of wheels is actuated by a worm originally, and of course the higher the current the quicker the revolutions. Count a number of revolutions so as to get a very exact determination in seconds of the period of one turn, and multiply this by the current; the product divided by a certain constant should be unity if the meter is direct-reading, and therefore gives the deviation from direct reading. The constant was 6·67 for the type of meter whose test I have just given you. As an example, with a current of 9·80 ampères the period of one revolution was found to be ·68 second, and $\frac{9 \cdot 8 + \cdot 68}{6 \cdot 67}$ gives unity for the meter at full load, this being the maker's constant.

To test a meter without removing it from the consumer's premises, the most convenient method is to connect in series with it a standard tested meter—say an Aron meter—and a recording voltmeter to get the average pressure of the supply. The checking meters must be placed on the main side of the meter under test, so that the consumer does not pay for the C_2 R losses in them.

I described a simple series parallel resistance just lately, and now give you a diagram of a more comprehensive one which was in use in the test-room of the works I was in. If you study the diagram you will soon

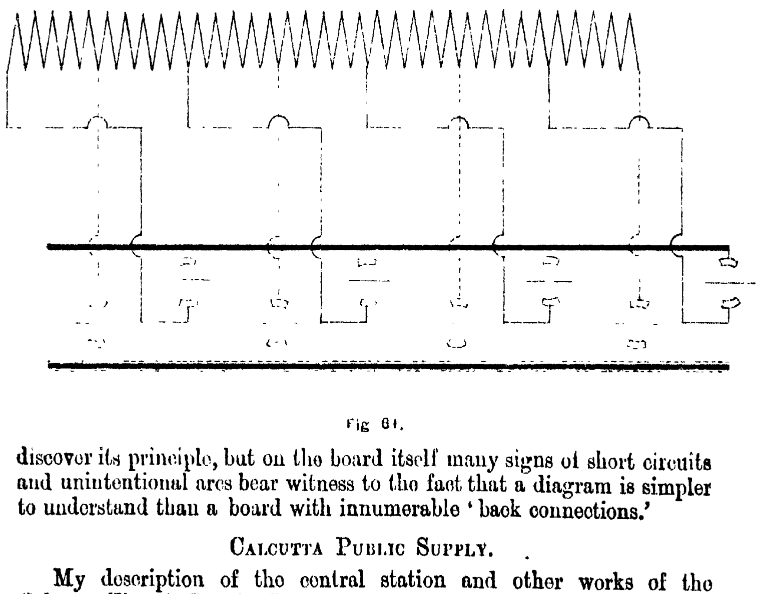


Fig 61.

discover its principle, but on the board itself many signs of short circuits and unintentional arcs bear witness to the fact that a diagram is simpler to understand than a board with innumerable 'back connections.'

Calcutta Public Supply.

My description of the central station and other works of the Calcutta Electric Supply Company must necessarily be a brief one, but some of the chief points have already been dealt with. The station is placed in Emambagh Lane and is thus fairly central, the area of supply being bounded by Circular Road, Chowringhee, and the river. The plant erected consists of the following—three 800 H.-P. Babcock and Wilcox water-tube boilers, with superheaters, economiser, and Babcock and Wilcox feed-water heater; two Willans-Crompton continuous current combined sets, with an output of 250 ampère at 450

volts and a speed of 450 revolutions; and two 'balancing sets' both consisting of a Willans engine driving two dynamos, each of which has an output of 85 ampères, 220 volts at 470 revolutions. This plant is therefore capable of maintaining about 7,500 16-C.P. 220-volt lamps alight simultaneously, and foundations are already laid for two more combined sets of far greater size. A battery of 248 cells is installed, each having 13 plates of Tudor make and the capacity being about 400 ampère-hours. There is a motor-generator for charging the top or regulating cells of this battery.

From the stations feeders are taken away to the feeding points of the system, which are eleven in number; two in Cornwallis Street, three in Chitpur Road, one in Theatre Road, one in Park Street, one near Government House, two in Dharamtalla and one near the Royal Exchange. All the feeders start underground on the Callendar system already described, some being converted into overhead after running some distance below ground. The distributing network runs through nearly every important street in the town, partly overhead and partly underground, and will of course be taken wherever consumers need it. Where an underground line terminates and continues overhead a special form of pole is put in, having a massive hollow cast-iron base in which the connections can be made. The conductors are carried up the poles on special insulators and taken out at the upper end to the overhead line, the top of the pole being hooded. Junctions in the Callendar mains are made in special junction boxes, which are afterwards filled in with bitumen or compound. House services are taken off both varieties of network, either through the wall below ground level from underground mains, or to a pair of insulators on the wall for overhead mains.

The meters used in houses are variously of Aron, Chamberlain and Hookham, and Ferranti type. Separate meters measure the power supplied for lighting and power purposes respectively, since there are two rates of charging, viz., 8 annas a unit in the former case and 4 annas in the latter. The lower rate for power is in consequence of the fact that a motor (driving, say, a fan, or a machine of any sort) will often run steadily for a large number of hours per day, and will therefore improve the "load factor" of the station. And, again, the motor load will not generally be at a maximum at the same time as the lights, and the actual output of the machinery is thereby increased without necessitating any increase of plant.

Legislation affecting Consumers.

The Company has the right to supply current within its area for all purposes by virtue of the "Calcutta Electric Lighting License, 1896," granted by the Government of Bengal under the powers of the "Calcutta Electric Lighting Act" (IX of 1895). The License, the Act, and the Regulations issued under the Act, together with the Government of India Act (XIII of 1887) and its regulations should be read in this connection, and I will draw your attention to a few points about them which particularly concern consumers in Calcutta.

Calcutta Electric Lighting Regulations.—The Calcutta regulations are taken almost *verbatim* from those of the English Board of Trade

they are divided into two parts—first those for securing the safety of the public (A), and second those for ensuring a proper and sufficient supply of electrical energy (B). We will take these two parts in order.

Under rule (1), the pressure of the supply delivered to any consumer at any pair of terminals may not exceed 250 volts, so large installations which take a three-wire supply off the mains of the Calcutta Company (whose outer pressure is 450 volts) have to be wired with separate and distinct circuits in the house, *i.e.*, without a common third wire.

Rule (14) specifies that lines exposed in such a position as to be liable to injury by lighting shall be efficiently protected, and this rule applies to most of the lines in Calcutta.

Under rule (19) an aerial line may not come within 5 feet horizontally or 7 feet vertically of any building, except where brought in for the purpose of supply. And the latter or service-lines must, under the following rule, "be led as directly as possible to insulators firmly attached to some portion of the consumer's premises which is not accessible to any person without the use of a ladder . . . . Every portion of any service line which is outside a building, but is within 7 feet from the building, shall be completely enclosed in stout India-rubber tubing." As to the wisdom of the latter half of this rule there is grave doubt, so far as Bengal is concerned. I consider that it is far wiser to have no pretence of insulation on such lines, since the rubber tubing will assuredly perish within a year or so of its erection, and thus offer a false security. At present, however, the rule holds good.

Under rule (38) the undertakers are bound to place a "fuse or other automatic disconnector" in each service line where it enters the consumer's premises, and it is to be "contained within a suitable locked or sealed receptacle of fireproof construction."

Under rule (41) a connection may not be made to a consumer's premises where the insulation resistance is so low that a leakage of one ten-thousandth part of the maximum current may take place, and if such a leakage occurs in a house already connected, it must be disconnected until the fault is rectified.

Of the B regulations for securing a proper supply, rule (2) provides that the supply must be constant from the time it is first given, except for testing purposes by arrangement with the proper authorities. In the latter case the stoppage may not under rule (3) exceed a maximum power of 20,000 watts, or affect more than 80 consumers at one time, and if its duration will exceed one hour, previous notice must be given to all consumers affected.

Under rule (4) the undertakers must supply at a constant "standard pressure" in any given distributing main, but a certain amount of deviation is allowable, namely, 2 per cent. in high pressure distribution and 3 per cent. in other cases. The "standard pressure" in Calcutta is 225 volts, so a 3 per cent. variation allows nearly 7 volts deviation on either side, from 218 to 232 volts in the mains.

Under rules (6) and (7) the undertakers must declare to any consumer, before connecting his premises on to the mains, at what constant pressure they intend to supply him at his terminals, and the variation from this declared pressure may not under any circumstances—except, of course,

unavoidable accident—exceed 4 per cent. The declared pressure here is 225 volts.

Calcutta Electric Lighting License:—So much for the regulations: let us now turn to the Calcutta Electric Lighting License, under the terms of which the Company here actually work, and consider such regulations as are of importance to the public.

Section 5 and schedule 1 define the area of supply, beyond which the undertakers may not erect works or supply energy. The area is bounded in two directions by streets having houses on both sides of them, but the houses on the outer side may not be supplied "otherwise than under a license" (section 6), being outside the area.

Section 9, sub-section (*c*), states that "the undertakers shall take all reasonable precautions in constructing, placing and maintaining their electric lines and circuits and other works of all descriptions, and also in working their undertaking so as not injuriously to affect, by fusion, or electrolytic action, any gas- or water-pipes or other metallic pipes, structures, or substances." This has especial reference to the conditions of electric tramway working, where an "uninsulated metallic return of low resistance" is generally used; where, that is to say, the leads are aerial lines and the returns consist of a conductor in the ground connected at short intervals to all the rails, which are themselves electrically 'bonded' together. The return therefore partially makes use of the earth also; if carelessly laid or designed, there may be large differences of potential between different points of it and the neighbouring pipes systems; corrosion then sets it and works havoc in the course of a few years. To guard against this, special regulations are generally drawn up binding tramway authorities to keep down their leakage and fall of potential in return wires to reasonable limits, and the following sub-section 9 (*d*) provides for regulations being made with this object, and also for the protection of "the electric wires, lines, and apparatus of other parties."

Section 17 and the corresponding schedule compel the undertakers to "lay down suitable and sufficient distributing mains for the purposes of general supply throughout" certain streets within a certain period (now expired). The following section, No. 18, is of considerable importance to the public, since it specifies that "In addition to the mains specified in the last preceding section, the undertakers shall . . . . lay down suitable and sufficient distributing mains, for the purposes of general supply, throughout every other street or part of a street within the area of supply, upon being required to do so," under a certain form of requisition.

Section 20 provides that the undertakers must keep these forms of requisition at their office, and supply them, free of charge, to any owner or occupier within the area. Such a requisition may be made by six or more owners or occupiers, and the undertakers are bound to comply with the request, except as specified in section 21, which I give *in extenso*.

Provisions on requisition by owners or occupiers.

"When any such requisition is made by any such owners or occupiers as aforesaid, the undertakers (if they think fit) may, within fourteen days after the service of the requisition upon them, serve a notice on all the persons by whom such requisition is signed, stating that they decline

to be bound by such requisition, unless such persons, or some of them, will bind themselves to take a supply of energy for three years, of such amount in the aggregate (to be specified by the undertakers in such notice) as will, at the rates of charge for the time being charged by the undertakers for a supply of energy from distributing mains to ordinary consumers within the area of supply, produce, annually, such reasonable sum as shall be specified by the undertakers in such notice: Provided that in such notice the undertakers shall not be required to specify any sum amounting to less than twenty per centum upon the expense of providing, and laying down, the required distributing mains, and any other mains or additions to existing mains which may be necessary for the purpose of connecting such distributing mains with the nearest available source of supply.

"Where such notice is served, the requisition shall not be binding on the undertakers, unless within fourteen days after the service of such notice on all the persons signing the requisition has been effected, or, in the case of difference, the delivery of the arbitrator's award, there be tendered to the undertakers an agreement severally executed by such persons, or some of them, binding them to take, for a period of three years at the least, such specified amounts of energy, respectively, as will, in the aggregate, at the rates of charge above specified, produce an annual sum amounting to not less than twenty per centum upon the expense of providing and laying down such distributing mains, or other mains as above mentioned, nor unless sufficient security for the payment to the undertakers of all moneys which may become due to them from such persons under such agreement, is offered to the undertakers (if required by them by such notice, as aforesaid) within the period limited for the tender of the agreement as aforesaid.

"If any difference arises between the undertakers and any persons signing any such requisition as to the reasonableness of the amount specified by the undertakers in their notice or as to the sufficiency of any security offered to them under the section, such difference shall be determined by arbitration."

Sections 40 and 41 deal with "supply," and as these also are of importance to the public, I give them as they stand:—

Undertakers to furnish sufficient supply of energy to owners and occupiers within the area of supply.

"The undertakers shall, upon being required to do so by the owners or occupier of any premises situate within fifty yards from any distributing main of the undertakers in which they are, for the time being, required to maintain a supply of energy for the purposes of general supply to private consumers under this license, or any regulations and conditions subject to which they are authorized to supply energy under this license, give, and continue to give, a supply of energy for such premises, in accordance with the provisions of this license, and of all such regulations and conditions as aforesaid, and they shall furnish, and lay, any electric lines that may be necessary for the purpose of supplying the maximum power with which any such owner or occupier may be entitled to be supplied under this licence, subject to the conditions following (that is to say), the cost of so much of any electric line for the supply of energy to any owner or occupier as may be laid

upon the property of such owner or in the possession of such occupier, and of so much of any such electric lines as may be laid for a greater distance than sixty feet from any distributing main of the undertakers, although not on such property, shall be defrayed by such owner or occupier."

Section 41.—"Every owner or occupier of premises requiring a supply of energy shall—

(*a*) serve a notice upon the undertakers, specifying the premises in respect of which such supply is required, and the maximum power required to be supplied, and the day (not being an earlier day than a reasonable time after the date of the service of such notice) upon which such supply is required to commence; and

(*b*) enter into a written contract with the undertakers (if required by them so to do), to continue to receive, and pay for, a supply of energy for a period of at least three years, of such an amount that the rent payable for the same at the rate of charge for the time being charged by the undertakers for a supply of energy to ordinary consumers within the area of supply, shall not be less than twenty rupees per centum per annum on the outlay incurred by the undertakers in providing any electric lines required to be provided by them for the purpose of such supply, and give to the undertakers (if required by them so to do) security for the payment to them of all moneys which may, from time to time, become due to them by such owner or occupier in respect of any electric lines to be furnished by the undertakers, and in respect of energy to be supplied by them:

"Provided, always, that the undertakers may, after they have given a supply of energy for any premises, by notice in writing require the owner or occupier of such premises, within seven days after the date of the service of such notice, to give to them security for the payment of all moneys which may, from time to time, become due to them in respect of such supply, in case such owner or occupier has not already given such security, or in case any security given has become invalid, or is insufficient; and in case any such owner or occupier fail to comply with the terms of such notice, the undertakers may, if they think fit, discontinue to supply energy for such premises so long as such failure continues:

"Provided, also, that if the owner or occupier of any such premises, as aforesaid, uses any form of lamp or burner, or uses the energy supplied to him by the undertakers for any purposes or deals with it in any manner so as to unduly or improperly interfere with the efficient supply of energy to any other body or person by the undertakers, the undertakers may, if they think fit, discontinue to supply energy to such premises so long as such user continues:

"Provided, also, that the undertakers shall not be compelled to give a supply of energy to any premises unless they are reasonably satisfied that the electric lines, fittings and works therein are in good order and condition, and not calculated to affect, injuriously, the use of energy by the undertakers or by other persons:

"Provided, also, that in the event of any alterations of, or additions to, any electric lines, fittings, or works within such premises, as aforesaid, all such alterations or additions shall be notified to the undertakers by the occupiers, before being connected to the source of supply, with a view to their being examined and tested.

"If any difference arises between any such owner or occupier and the undertakers as to the reasonableness of the amount of any security required to be given, or as to the sufficiency of any security offered under this section, or as to the improper use of energy, or as to any alleged defect in any lines, fittings or works, such difference shall be determined by arbitration."

The consumer may not alter his maximum power, fixed under the sub-section 41 (c) above, without due notice to the undertakers, under section 42, which also defines the phrase "maximum power" and provides for the settlement of disputes with regard to it.

With regard to price, section 45 gives three alternative methods of charging—

(1) "By the actual amount of energy so supplied," *i.e.*, the number of watt-hours as measured by an integrating meter. Under section 1 of the fourth Schedule, the undertakers may charge the consumer at the following rates per quarter, "for any quantity up to twenty units, Rs. 20 only, and for each unit over 20 units, annas twelve only" (a unit is one thousand volt ampère-hours, or one thousand watt hours).

(2) The second method is "by the electrical amount contained in such supply." The rate of charging is the same as above, the quantity of energy "being taken to be the product of such electrical quantity and the standard pressure at the point of junction of the distributing mains and the service lines by which he is supplied" (Schedule IV, section 2). The "electrical quantity" is measured in ampère-hours, and this is actually the method in most general use here.

(3) The third method is "by the number of hours during which the supply of energy is actually used by such consumer and the maximum power with which he is, for the time being, entitled to be supplied." The quantity of energy, which is chargeable at the same rates as above, is in this case "calculated on the supposition that the consumer uses the maximum power specified by him under the provisions of this license during all the hours that he has used the supply" (Schedule 4, section 3). It is seldom that it would pay a consumer, except for street lighting purposes, to be charged on the last method, and he may demand to be charged by the actual quantity of energy, if he chooses.

Under section 51 the undertakers, or any consumer, may demand to have a meter certified upon paying the necessary fees; a certified meter is "to be of some construction and pattern, and to have been fixed, and to have been connected with the service lines, in some manner

approved of by the Local Government, and to be a correct meter." The only type of meter definitely approved of by the English Board of Trade is, I believe, the Aron meter, but there are many other types that read fairly correctly and are not of such delicate construction, and the latter are in very general use. The consumer is liable, under section 52, either to pay for the meter or to pay for hiring it, and he also has to pay the cost of fixing it, connecting it to the service lines, and procuring it to be certified. Hence he almost invariably elects to have an uncertified one!

Section 53 makes the consumer liable to a penalty if he connects or disconnects his meter without 48 hours' notice to the undertakers.

If the consumer owns his meter he must, under section 54, keep it in repair, or the undertakers may cease to supply energy through it. In such cases the undertakers may test the meter at any time, and if it proves incorrect the consumer has to bear the cost, while if correct, the undertakers bear it.

When a meter is let for hire by the undertakers they may make a mutual agreement with the consumer as to the terms for hire and keeping in repair under section 55; if they make no such agreement they must keep it in repair at their own expense, or the consumer can, in default, refuse to pay rent while it is out of repair (section 56).

Differences as to the correctness of the meter are to be settled by the electric inspector, or by the Local Government, under section 57.

If the undertakers change the method of charging for energy, any consumer affected by the change can obtain from the undertakers "the reasonable expenses to which he may be put in providing a new meter" under section 58.

Under section 59 the undertakers may place other meters or instruments on a consumer's premises "for the purpose of ascertaining or regulating either the amount of energy supplied to such consumer or the number of hours during which such supply is given, or the maximum amount of such supply or any other quantity, or time, connected therewith," but the approval of Government is necessary, and the whole cost has to be borne by the undertakers, including the cost of the energy wasted in the instruments. It is not unusual in the case of disputes to connect up a recording ampère meter, or voltmeter, or both, as a check upon the correctness or otherwise of the amount of energy supplied or the terminal pressure.

Where the undertakers let out a meter, or lay distributing mains under a requisition, or are otherwise entitled under the license to obtain security, "such security may be by way of deposit, or otherwise, and of such amount as he and the undertakers agree on, or, as in default of agreement, may be determined, on the application of either party, by a Court of competent jurisdiction, which may also order by which of the parties the costs of the proceedings shall be paid, and the decision of the said Court shall be final and binding on all parties: Provided that where any such security is given by way of deposit, the undertakers shall pay interest at the rate of five rupees per centum per annum on every sum of ten rupees so deposited for every six months during which the sum remains in their hands" (Section 66).

LECTURE VI.

Darjeeling Municipal Electric Supply.

A description of the Darjeeling installation cannot fail to be of some interest to you, since it is worked by water-power, and will probably be the forerunner of other similar undertakings. It was my good fortune to be in charge of the construction of these works three years ago, and it was recently my misfortune to see the havoc wrought by the cyclone on some parts of it, though I am bound to say that, on the whole, the damage was far less than might have been reasonably expected, and the plant was worked again within seven weeks I shall give you a general description of the scheme which I wrote at the time for publication, interspersing some notes here and there. The diagram (Plate 3) shows the general plan of the works.

The undertaking, which is owned by the Municipality, is worked on the alternating current system, the generating station being some $2\frac{3}{4}$ miles from the town and about 3,500 feet below it.

Hydraulic works.—"Water is collected from two *jhoras* or hill-streams, and led in galvanised iron troughing to a large reservoir situate midway between the two sources of supply, but before entering this reservoir the water flows through two small settling tanks. From the reservoir the water is carried in cast-iron pipes to the pentrough, a small tank on the same level and of the same depth as the reservoir. From the pentrough it is taken to the turbine house by two steel pipes, which connect up to two Girard turbines, the tail race running through an arch in the wall, and thence discharging into the *jhoras*, which meet at this point. The streams from which the supply is drawn are named the 'Kotwali' and 'Hospital' *jhoras*. The former is a fairly manageable stream, giving about 100 cubic feet per minute at the driest part of the year, which is in March. In the rainy season the quantity is from five to ten times this amount; but as the bed of the stream is fairly level at the point where it is tapped, there is seldom a high enough velocity to endanger the head-works." (Nevertheless, the cyclone of last September caused such a rush of water that the bed of the stream was scooped out to a depth of some 20 feet below the head-works, rendering the old site useless!)

"At this point the rocks on the bank were blasted away until a small tank was formed, into the top end of which all or part of the stream could be turned. It could then be either led into the drain or discharged back into the stream, the exits being regulated by sluices. The drain is open and square, 1′ 3″ × 1′ 3″, made of galvanised iron, and cross-stayed every 3 feet. The gradient of the road is $1\frac{1}{2}$ inches in 10 feet, or 1 in 80, which gives a sufficient velocity to carry more than the whole of the water required for the turbines when working at full load. This drain road is 1,500 feet long, the first 800 feet being cut in the side of a gently sloping spur, consisting chiefly of soft soil. The heavy rains during the construction of this part often washed 20 feet or 30 feet of the road completely away, and in such cases revetment walls were built, and surface drains made to carry off the water. The drain next crosses a very small stream at the point where it falls over a

cliff about 60 feet deep, and the cliff continues for about 100 feet as a vertical precipice above and below the road level. It was at first intended to run the drains on brackets here, but finally a shelf was blasted out of the face of the rock, giving a clear road of about 3 feet in width. From this point onwards the construction was easier, and just before entering the settling tank there is a bye-pass in the drain, through which leaves and rubbish can be run off before the supply is used. This settling tank is 20′ × 8′ × 8′ deep. It is merely for the purpose of collecting the large stones and sand which come down from the stream at flood-time.

"The Hospital *jhora* was much more troublesome than the smaller stream. In a dry season the quantity of water may go down as low as 150 cubic feet a minute, but in the rains it is subject to the most sudden and violent floods: when these occur the volume of water will increase 30- or 40-fold in a few minutes, carrying enormous rocks down with it, and continually changing the stream's course where the bed is wide. At the point where the water is taken off for use the stream has a steep gradient and a semi-circular course, leaving a fairly large area of rock and sand high and dry, supported all round by rocks huge enough to ensure permanency. It was found useless to attempt tapping this stream in the same manner as the Kotwali *jhora*, so a small diversion of the stream was made and the water so diverted was led into a small but very strong stone tank about 3 feet deep, from which it could, as before, be directed either into the drain or back into the *jhora*. In heavy floods the water of this stream carries so much sand with it that it is not possible to prevent the drain occasionally getting blocked, and the settling tank will get full up with sand and stones in a few hours." (These head-works and their site and a considerable length of the adjoining drain road were entirely demolished in the cyclone despite their assured permanency !)

"The course of this drain road is mostly along the face of cliffs or very steep slopes on the hillside. The gradient is the same as that of the other road—that is about 1 in 80. Seven or eight small streams are crossed by dry stone bridges, and in each case a short drain is laid, by which these streams can be led into the main drain. In case of a breakdown at the head-works, or in case the water is very full of sand after heavy rains, these small streams are able to supply the whole needs of the plant. About a quarter of this road is cut and blasted out of the solid rock, and of the remainder nearly half is supported on revetment walls of dry stone. Several of the larger revetments are about 15 feet high, as the steepness of the bank renders it necessary to cut far down in order to get room for the foundations. Five or six enormous boulders, which happened to lie across the line, had to be blown up with dynamite, and in parts the hillside slopes down at an angle of 85°, but this being covered with jungle is prevented from slipping frequently. The drain is 1′ 6″ × 1′ 3″ rectangular, made similar to the other one, the arrangements of the settling tank and bye-pass being also the same as those of the smaller *jhora*. Its total length is 30,00 feet.

"The large reservoir is 112′ × 47′ × 8′ deep, built of stone, with a slope of 1 foot on the inside of the walls. The concrete bottom is

sloped from all sides towards the outlet to facilitate cleaning out. A wide overflow weir is made at 8 feet depth, but this can be closed to give an extra 1 foot of storage depth if required. The ground on which the tank is built had a slope originally of 1 in 5, and the excavations went down about 16′ at the top end. The ground consisted of earth and boulders with a little continuous rock, all very firm and reliable as a site.

"A 24″ cast-iron outlet pipe is let through the wall, so that its centre is level with the bottom of the tank, and a pocket 6′ × 4′ × 2′ deep is made in the tank at this point to prevent the possibility of stones being drawn into the pipe. A Stone's improved sluice valve is fitted to this exit, but this is only used when the pentrough requires cleaning. The pipe runs dead level to the pentrough, a distance of some 400 feet. The pipes are in 12 feet lengths, and weigh $1\frac{1}{4}$ tons each, the joints being made with oiled gasket and lead strips caulked in cold.

"The pentrough is a small tank, 20′ × 4′ × 10′ deep, the top being level with the top of the reservoir wall. Owing to the nature of the hill it had to be built with only the foundations below ground level. The walls consequently are very thick, and after completion an embankment of rammed earth and stones was built round it. A very strong galvanised locket-work strainer of $\frac{1}{2}$″ mesh is placed across this tank to guard the turbines, and the tank itself is covered in. From this point two 15″ pipes are run down to the turbine house. These are built in 20 foot sections, of $\frac{3}{16}$″ steel double rivetted, with stamped steel flanges rivetted on, and joints are made by bolting the flanges together on to a pure rubber washer $\frac{1}{8}$″ thick, with fourteen $\frac{5}{8}$″ bolts. Each pipe is controlled at the pentrough by a Stone's improved sluice valve.

"The total length of the pipe road is about 720 feet; in plan there are two bends, one of 28° about two-thirds of the way down, and one of 90° at the turbine house, while in vertical section the slope of the pipe line is fairly even. The bends are of cast-iron, tested to 250lbs., and the flanges of the steel pipes are altered at these points to take ten $\frac{5}{8}$″ bolts. The ground is very uneven, and at different points there are cuttings up to 12 feet deep in very rocky ground, and embankments up to nearly 20. The slight deviations from uniform slope are taken up by means of wedge-shaped iron flanges placed at the joints. No special provision is made for expansion in these pipe lines; they are covered up from the direct rays of the sun, and water is kept in them always, so the amount is negligible. The pipes are anchored down to the ground by long bolts at various points." (All the pipe-works and tanks remained undamaged by the storm.)

Machinery.—"We now arrive at the turbine house. This is a *pucka* stone building, 20′ × 20′, with an iron roof. The site, though convenient, was unfortunately very sandy, soft and wet, so a foot of Portland cement concrete had to be used as a foundation under the whole building." (This extra foundation probably saved the building from total destruction, since the whole of the machinery was found completely buried in mud after the storm, though only one wall gave way.) "Two 8″ × 4″ girders are built in, on which half-ton chain blocks are hung for lifting parts of the machinery, if necessary. The two turbine sets

are placed with their main shafts parallel, and are bolted down to a stone-work foundation $5\frac{1}{2}$ feet deep. The supply pipes are led in through doors, so that all parts of them are easily accessible. The tail-races are in one straight line, with a pit 4′ 9″ deep under the exhaust of each turbine. After going through the wall, the water is carried in a stone-built drain for about 10′, and then in a trough of galvanised iron, which carries the water clear into the *jhora* thereby preventing any danger of causing landslips.

"Each turbine is rated to give 100 H.-P. using 250 cubic feet of water per minute, under an effective head of 275′, the actual head being 277′ from the bottom of the pentrough. The turbines are fitted with a hydraulic governor, which acts on the sluice valve controlling the orifices. These are four in number, and are spaced so that if all are open they act on four separate vanes of the turbine; at half load only two will be open, and at quarter load only one, but as they act independently, the efficiency is the same at all loads. This is an important matter in a small station, where the hours of running are long and the load factor is low. A small hand-lever on the governor suffices to start or stop the turbine, which obviates the necessity of shutting the large sluice valve on the main pipe. Spring safety relief valves are placed on the main, just outside the turbine house, set to blow off easily in case the sluice is suddenly closed, the pressure due to the head being 120 lbs. to the square inch. Turning now to the electrical, arrangements, each dynamo shaft is direct coupled to its turbine shaft, and the two machines are in each case mounted on one cast-iron bed-plate; the whole making a very compact piece of plant, weighing about 3 tons and about 11′ × 4′ × 4′. The dynamos are 65 k-w Crompton-Brunton alternators, the output being 28 ampères at 2,320 volts. The exciter armature is keyed direct on to the alternator shaft, and it has an output of 15 ampères at 35 volts. Regulating resistances are placed as usual in the main and shunt coils, with multi-contact switches. The switch-board has a panel for each dynamo, each containing a double pole cut-out, double pole switch, ampère meter and transformer voltmeter. A lightning discharger is placed inside the house, protecting the top wire of the line. The remaining details of the turbine house are a cupboard of spare parts, spanner board, and a table, which fill up nearly the whole available space. It is lit by 35 volt lamps off the exciter.

Mains.—"The high tension leads are taken from the switch-board to a pole outside, where they are connected to the main line. This consists of bare hard-drawn No. 7 copper-wire, run on two-part oil insulators fitted to single tubular brackets, placed a foot apart on the poles to prevent any chance of the wires swinging together in a wind. The poles are of the Indian Telegraph Department, A.B.C. pattern, 23′ 6″ high, and stayed at all angles Wurts double pole lightning-arresters are placed every half mile on the line, the earth terminal being connected to a steel wire, which is run along the extreme top of the poles and soldered to them. The high tension line takes a fairly direct course of about $2\frac{3}{4}$ miles to Darjeeling, rising some 3,500 feet on the way. The spans vary from 150 feet to about 400 feet where a large stream is crossed. In the station the bare wire is replaced by high tension cable, insulated and suspended according to B.O.T. rules. The

suspending wire is $\frac{3}{16}$ galvanised steel, and porcelain suspenders are used.

"The main branches off to three distributing points, at each of which there is a small galvanised iron shed containing the transformer and the circuit switch-board. The transformers are of the Crompton-Brunton type, two being 20 k-w and the other 15 k-w. The pressure of distribution is 230V. Pilot lamps are placed in the sheds and lighting-arresters are coupled over the secondaries of the transformers.

"The street-lighting distribution is carried out also with bare wire on A. B. poles and ordinary insulators. There are 200 16-C.-P. lamps in waterproof fittings on galvanised brackets, spaced about every 200′ in the main thoroughfares."

The street lamps are carried on tubular brackets clamped on to the poles. The tubes project some distance into the pole and thus prevent water getting on to the conductors. The leading in wires are, of course, insulated, and they run up inside the poles until opposite the bare mains. Here they emerge, but no proper provision is made to prevent moisture running down through the holes. A very short downward bend of pipe would have been the best arrangement, or failing that a water-tight bush.

"In addition to the incandescent lighting there are two 3,000-C.-P. (nominal) arc lamps—one over the band-stand on the Chowrasta, and one on a 45-foot pole in the market-place. These lamps are run off special transformers, reducing the low tension mains pressure to that required for the lamps.

"The straining up of the mains was done by the rope-and-pulley method, as the linesmen were only used to that and could not grasp the principle of the draw-vice. The B.O.T. rules were relaxed in the matter of crossing over roads and proximity to houses, for in the bazaar parts the roads are very narrow, and never go more than about 100 feet in a straight line; a single span will sometimes cross and recross such a road at various angles. Considerable difficulty was found in avoiding the telegraph lines at a few points, but there has been no 'interference' at all since working started.

"A number of private installations have been carried out, the heavy mains for their supply being run on C.D.E poles of the same pattern as the smaller ones. The street-wiring is very little disfigurement to the town, certainly no more so than the wires of the Telegraph Department, and of course in a place so liable to landslips and heavy rains no other system was feasible.

"The excavation of the tank, &c., was begun in March 1897, and the street-wiring about two months later. Only one turbine and dynamo were erected at first, and these were finished and coupled to the circuit on November 9th. A trial of the pipes was made that morning and a few leaks were put right, then the turbine was tested and found satisfactory, and on the next night, November 10th, the installation was formally inaugurated by the Hon'ble C. C. Stevens, Acting Lieutenant-Governor of Bengal. Regular running began on December 1st, after which there was no interruption to the supply of any importance" until the cyclone! "The second set of plant was erected in January and is kept simply as a stand-by in case of a breakdown. The contract hours of running are 7 P.M. to 5 A.M., but actually the plant is started

up as soon as it begins to get dusk, for the benefit of private consumers, the street-lamps being switched on just before dark."

Lightning-arresters.—To this general description I will add a few remarks on special points. First, as to lightning-arresters, several have been tried with varying measures of success. About every half mile on the high tension lines there are two Wurts arresters in series, the pressure of 2,300 volts being greater than one is constructed to deal with. These arresters have three cylinders of an alloy which is not capable of maintaining an arc; the two line-wires are connected to two of them and the third is earthed. Should the stress in either line become great enough a discharge to earth occurs, but the dynamo current is unable to follow, since the arc cannot be maintained. Despite the use of these arresters a transformer was twice 'burnt out' by lightning, so the American device of adding a 'kicking coil' was tried with success. The arrangement consists in winding the conductor itself into an inductive coil of a few turns, just beyond the arrester. Ordinarily this coil hardly affects the working, but the oscillating discharge induced in the wire by a close lightning flash cannot overcome the self-induction of the coil, and so jumps the small air gap between the arrester cylinders. In addition to these devices a form of 'bird-cage' arrester was tried most successfully in the turbine house and elsewhere. This consists of a conical shaped metallic grating, connected to the line, placed within an inverted conical grating, connected to earth, as shown

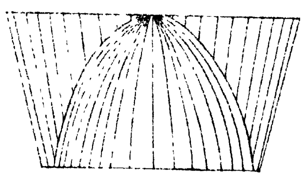


Fig. 62.

in the sectional diagram (Fig. 62). If a discharge takes place the consequent arc is driven upwards until it breaks from excessive length.

Calculation of conductors.—We will consider next the losses in transmission and the calculation of the conductors. It was specified that the plant should be capable of maintaining 200 16-C.-P. street lamps and 1,200 8-C.P. lamps in houses.

Now 200 16-C.-P. lamps at 64 watts require...	12,800 watts.
And 1,200 8-C.-P. „ „ 32 „ „ ...	38,400 „
The total power at the lamps is therefore ...	51,200 „

Allowing about 4 per cent. for loss in the distributing network we find that the transformer secondary coils must be capable of giving 53,000 watts between them. With an over-all efficiency of 95 per cent. for the transformers—it was probably higher—the power delivered to the primary or high tension side of the transformers must be about 56,000 watts.

The transformers, three in number, were to be supplied at a pressure of 2,000 volts at their terminals and to transform it to 230 volts. The

current will therefore be, on the low tension side, $\frac{58,000}{230} = 230$ ampères and on the high tension side $\frac{6,000}{2,000} = 28$ ampères.

Since the dynamos are of 65 kilowatts output the loss in transmission on the high tension line is 9,000 watts, or about 14 per cent. The volts lost in the line at full load will therefore be $\frac{9,000}{28}$ or 320, and the dynamo volts 2,320.

$$(2{,}320^{v} \times 28^{a} = 65{,}000 \text{ watts.})$$

Now the resistance of the line must by Ohm's law be $\frac{320}{28}$ (*i.e.*, lost volts divided by current) or $\frac{9,000}{28^2}$ (*i.e.*, watts divided by the square of the current), that is, 11·43 ohms. Its total length is about 12,000 yards, so we require a conductor whose resistance is about $\frac{12}{11\cdot43}$, or 1·05 ohms, per 1,000 yards. No. 7 S.W.G. copper wire nearly fulfils the requirement, its resistance being 1·006 ohms per 1,000 yards, which is increased to about 1·02 ohms for the hard-drawn wire used on aerial lines.

The pressure on the L. T. side of the transformers is, as I have told you, 230 volts; the lamps are 220-volt ones, and the excess of pressure makes up for some of the loss in the distant parts of the network, while only giving about 4½ per cent, too high pressure to near lamps. Under the conditions of the contract the minimum allowable pressure was 210 volts, or, say, 4½ per cent. below normal.

The street lamp circuits were mostly run with No. 12 S.W.G. hard-drawn copper wire, and the longer ones were generally so calculated that the maximum drop should not exceed 12 volts, giving an actual pressure of about 230–12, or about 218 volts. In calculating the wires for street networks, remember that the conditions are not the same as when dealing with feeders. For in a feeder the whole current traverses the full length, whereas in a street-lighting circuit the lamps are dotted along at intervals, and the total current only reaches to the first lamp. Where lamps are equally distributed on a pair of wires the actual drop in pressure is just half what is found by C × R.

In the installation at the "Shrubbery" there are a number of lights in the grounds carried on trees. The brackets carrying the water-tight fittings are clamped round the trees, the wires being led in through protected apertures, and the mains supplying current to them are carried overhead from the street, concealed among the trees.

Works Notes on Tests, &c.

I cannot do better than finish off my lectures by giving you the benefit of some extracts from the note-books I have always made a point of keeping. It is more than probable that none of you will have to do the precise tests or use exactly the same methods that I describe, but they will perhaps help you when similar circumstances arise.

Tests of dynamos during manufacture.—When a dynamo or motor is built, it is necessary to test whether it does what is required of it, and comes up to specification generally. The process begins at an early stage, for if errors are not rectified at first, they are difficult to correct when the machine is finished. As each magnet coil, main or shunt, is wound, the resistance of it is taken, to see that it comes

approximately to the calculated value. The first or 'alternator test' of the armature occurs when the windings are on, but before the commutator is fitted. Taking, as an example, a continuous current armature having 66 coils, the start of one coil and finish of the next are successively coupled together all round, ready to connect to the commutator. A certain number of the coils, say 6, are now disconnected from the rest and a small current from a fairly low-volt testing alternator is sent through these 6 coils. This induces an E.M.F. eleven times as great in the remaining series of coils, and if there is a defective coil, with a short circuit, it will burn up. The process is repeated at one other point so as to give the six coils the same test as the rest have had.

After the commutator has been connected up, the 'galvanometer test' is made to see that the coils and connections from one commutator segment to the next are all equal. Two wires are placed along exactly opposite segments and bound on with tape, a current being thus passed through the two halves of the armature in parallel. Two other wires are connected at one end to a galvanometer, and the other ends are then put successively in contact with each adjacent pair of segments. The deflections (due to the fact that there is a small difference of potential between each pair) should all be equal, and any smaller than the rest is probably due to a bridge of solder having partially short-circuited the segments, or to a badly soldered connection. (If the deflection produced is too great to read either the current can be reduced or the galvanometer "shunted" by a resistance.)

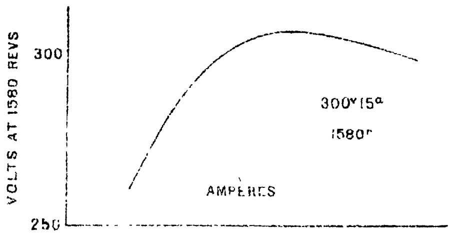
When the parts are complete and put together, a high-volt 'insulation test' is taken. Two wires are brought from a testing transformer, having a potential difference of 1,000—10,000 volts between them according to the nature of the machine under test. One is connected to the bed-plate or spindle, and the other is touched on to the commutator through a long thin fuse. If all is well, there will only be a static discharge of sparks, and the fuse will not rupture. The magnet coils are then tested in the same way.

Tests of completed machines.—The next thing is to test the machine itself under working conditions. Whether dynamo or motor, it is usual to keep it at full load for about six hours, and then to "run it down," that is to say, reduce the load and take the necessary readings at each. The following points must be looked to:—the machine should run sparklessly at all loads; the armature should run perfectly true; the bearings should keep cool, and the temperature of no part of the machine should be excessive at the end of the run. It is usual in England to specify an allowable rise of 70° above the atmospheric temperature, but this allowance is distinctly too high for the plains of India, and 50° would be better.

The procedure when "running down" a machine differs of course according to its nature, and I shall describe this for each type, giving a 'characteristic curve' of an actual machine as an illustration. 'Taking readings' in each case implies a simultaneous determination of volts, ampères and speed.

Series wound generator (closed coil).—Take readings at the correct (full load) volts and ampères, setting the brushes in the most favourable

position. Then, without again shifting the brushes, increase the load above normal some 50 or 60 per cent., to find the droop of the curve, and after this take lower readings at $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ load, keeping speed constant. Note that in a series machine the external circuit must be switched on to start with, since there will otherwise be no field. For the same reason it is evident that a 'no-load' reading cannot be taken. The characteristic curve is obtained by plotting the E.M F., corrected for constant speed, against the current. The curve shewn is that of an



Curve of series-wound generator.

Fig. 63.

arc lighter giving 15 ampères at 300 volts when driven at 1,580 revolutions a minute. The actual readings taken were as follows:—

Speed.	Ampères.	Terminal volts.	Volts corrected to 1,580 speed.
1,614	16·9	315	308
1,580	20 0	303	303
1,620	22 6	307	300
1,550	14·0	297	303
1,554	10·6	301	306
1,560	6·8	285	285
1,564	4·3	256	259

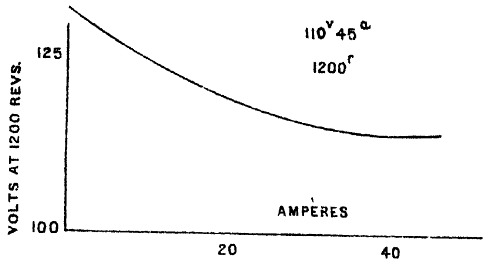
To plot the E.M.F. "corrected for speed" is necessary, since it is never possible to keep this latter absolutely constant.

$$\text{Corrected E.M.F.} = \frac{\text{Observed E. M. F.} \times \text{correct speed.}}{\text{Observed speed.}}$$

Speeds are taken by a counter, for half a minute in each case; meanwhile volts and ampères are read on the potentiometer.

Shunt-wound generator.—Take readings at correct volts and ampères and then reduce the load gradually to zero, keeping the speed constant and letting the volts run up. Plot the curve of E M.F., corrected for speed, against the current as before. The curve (Fig. 64) given at the top of the next page is that of a machine giving 110 volts 45 ampères at 1,200 revolutions, the actual readings being as follows:—

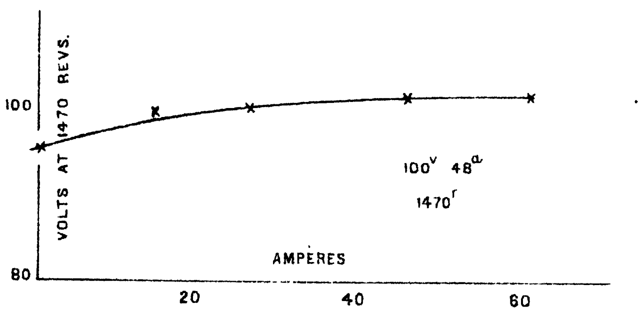
Speed.	Ampères.	Terminal volts.	Volts corrected to 1,200 speed.
1,164	45 8	111	113
1,148	20 5	114	119
1,122	0·	123	131



Curve of shunt-wound generator.

Fig. 64.

Compound-wound generator.—Take readings at correct volts and ampères; then reduce current, keeping E M.F. constant by altering, if necessary, the speed. Plot the curve of E.M.F., corrected for speed, against current. The curve shewn is that of a machine giving 100 volts



Curve of compound-wound generator.

Fig. 65.

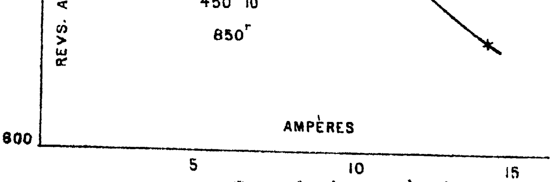
48 ampères at 1,450 revolutions. You will notice that it 'compounds up' some 6 volts at full load, just as the machine for our model installation (*vide* Lecture 4) would have had to compound up 3 volts in order to compensate for the loss in the main. The actual readings under test were as follows :—

Speed.	Ampères.	Terminal volts.	Volts corrected to 1,470 speed.
1,468	60·7	100·7	100 9
1,470	46·0	100 7	100 7
1,480	26·3	99·6	99·0
1,504	15·4	100·8	99·6
1,554	0·	100·0	91·6

In making tests of any of the foregoing, the machine would be driven by belting from the works' engine (or an electric motor), except in the case of dynamos for direct coupling, which are run with their own engines as a rule. Very large sets will sometimes be run at full load for 24 hours, though 6 hours is generally sufficient. The current is absorbed by water resistances or by large resistance coils, which are generally built up of spirals of band iron to give a large heating surface. Series-parallel switching arrangements will be coupled so as to give a wide range of regulation, and the current will also pass through a standard resistance to enable measurements to be taken on the potentiometer.

Coming now to the consideration of these types of machines when tested as motors, they are then loaded up by being coupled to a dynamo, whose output regulates the load.

Series-wound motor.—To couple up a series generator to run as a motor the only thing necessary is to cross the brush leads; the rotation will then retain its original direction. In taking the test, take readings at full load and correct E.M.F., then reduce the load until the motor is "running light" (*i.e.*, merely rotating, without driving anything; the belt being thrown off), keeping the E.M.F. constant all the time. Plot the curve of speed, corrected to constant E.M.F., against current. The curve I give you is that of a machine with an input of 450 volts 10 ampères, which, with 87 per cent. commercial efficiency, gave $5\frac{1}{4}$ B.H.P. at 850 revolutions—



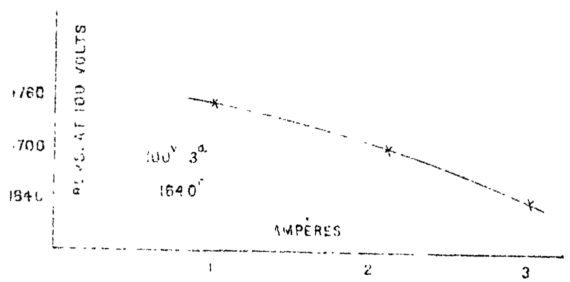
Curve of series-wound motor.

Fig. 66.

The actual readings under test were as follows:—

Speed.	Ampères.	Terminal volts.	Speed corrected to 450 volts.
740	14·3	451	738
800	10·5	427	842
1,030	7·4	472	983

Shunt-wound motor.—A shunt dynamo will run equally well as a motor without any alteration of the connection whatever. In testing, take readings at about 20 per cent. above normal full load and at correct volts, then reduce load gradually until machine is running light, keeping the volts constant and letting the speed run up. Plot the curve of speed, corrected to constant E.M.F., against current. I give you the curve of a little ¼ B.H.P. shunt motor, with an input of 100 volts 3 ampères and a speed of 1,640 revolutions:—

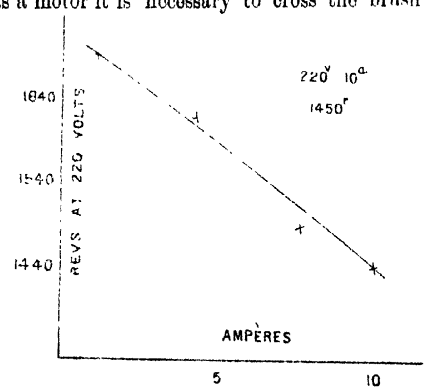


Curve of shunt-wound motor.
Fig. 67.

The readings under test were as follows:—

Speed.	Ampères.	Terminal volts.	Speed corrected to 100 volts.
1,680	3·0	102·5	1,640
1,718	2·1	101·0	1,700
1,786	1·0	102·	1,750

Compound-wound motor.—In coupling a compound-wound generator to work as a motor it is necessary to cross the brush leads in order to



Curve of compound-wound motor.
Fig. 68.

alter the main coils, and also to cross the shunt leads in order to bring them back to the same conditions as before the brush leads were altered. In testing take readings at full load and correct volts, then reduce load until machine is running light, keeping volts constant and letting

speed run up as before; plot the curve of speed, corrected to constant E.M.F., against current. The curve of a 2 B.H.P. compound motor is shewn in Fig. 68, the input being 220 volts 10 ampères and the speed 1,450 revolutions. The readings on test were as follows:—

Speed.	Ampères.	Terminal volts.	Speed corrected to 220 volts.
1,452	10·1	222	1,440
1,504	7·6	222	1,490
1,620	4·3	220	1,620
1,700	1 2	222	1,685

In the curves of series and shunt motors you will notice that the characteristic shows a fall of speed in each case with increased current. The compound motor therefore naturally combines the two, and also shows a drop in the same way. Evidently, then, if we set the main coils to act against the shunt we can get a machine that will keep its speed constant under all loads, and such a machine is called a *differentially wound* motor. Only a very few turns of the reversed main are needed. Such motors are tested in the same way as compound

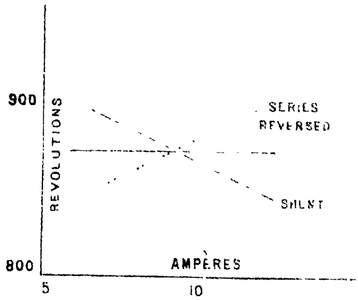


Fig. 69. Curve of differentially wound motor.

motors. I have no actual test to show you as an example, but the subjoined curve (Fig. 69) explains what happens.

When a machine is sent out from the works a characteristic curve will usually be sent with it, and also some of the test readings, and for guidance in the design of similar machines various particulars are also worked out on the works' test-sheets for record. The following formulæ are in some cases obvious, but their inclusion here is, at least, harmless.

In dynamos—

Corrected volts $= \frac{\text{observed volts} \times \text{correct speed.}}{\text{observed speed.}}$

Brush volts = (Rm. hot × external current) + terminal volts uncorrected: where Rm. is the resistance of the whole main winding as coupled for test. In a shunt machine this factor is absent and therefore Brush volts = terminal volts uncorrected.

Shunt current = brush volts ÷ shunt resistance.

Armature current = External current + shunt current.

Armature volts = brush volts + (resistance of armature hot × armature current).

In motors—

Corrected speed $= \frac{\text{observed speed} \times \text{correct volts.}}{\text{observed volts.}}$

Brush volts = terminal volts uncorrected − (Rm. hot × external current). In the case of shunt motors, Brush volts = terminal volts uncorrected.

Shunt current as in dynamo.

Armature current = external current − shunt current.

Armature volts = brush volts − (resistance of armature hot × armature current).

For both motors and dynamos the "ampère-turns" on one arm of the magnets for either main or shunt are determined as follows:—

If all coils are in series, multiply current by total turns of wire on one arm.

If there are two coils only, and in parallel, multiply ½ the current by total turns of wire on one arm.

If there are four coils, all in parallel, multiply ¼ the current by total turns of wire on one arm.

If there are four coils, two series, and two parallel, multiply ½ the current by total turns of wire on one arm.

Useful memoranda.—There are many factors that should be borne in mind in designing or using a dynamo, and the following are worth jotting down:—

To allow for the thickness of insulation on a conductor—

For double cotton covering	on	square wires	add	·03	inch	to the	diameter.
,, ,, ,,	,,	round	,,	·02	,,		,,
,, single ,,	,,	,,	,,	·01	,,		,,
,, double silk	,,	,,	,,	·008	,,		,,

From these figures it is easy to work out the number of turns of a given insulated wire which can be wound per inch of available width.

In a ring-wound armature the number of commutator parts must be an integral multiple of the number of radial arms, otherwise the turns will not go on evenly, and the armature will be out of balance.

If there is more than one layer of wire, except in sunk winding, the turns per section or coil must be an integral multiple of the number of layers, or the winding will not be mechanically firm.

The maximum output in watts of an armature varies as the length of the core and as the square of its diameter.

There are many rules for finding the direction of a current and its magnetic effect, &c., of which I give you three useful ones. Suppose you have a current passing in a wire, and you wish to know the direction in which it is travelling; place a small magnetic compass under the conductor, pulling the latter round until more or less in the magnetic meridian. The north pole of the needle will be deflected 'clockwise' if the current is travelling from north to south; to fix this easier in the mind Crompton put it in the form of a mnemonic rule, that current entering at **S**outh turns **N**orth seeking pole **O**ver to **W**est, and recollection of the word 'snow' formed by the four index letters will always at once bring back the rule.

If you have a solenoid and require to know in which direction its magnetic poles will be, when energised in a given direction, the simplest rule is to imagine you are swimming with the current from the positive to the negative pole, when the north pole will be on your left hand.

Then there is Fleming's most useful rule for finding the direction of the induced current in the revolving armature of a dynamo. Hold the first and second fingers and thumb of the right hand at right angles to one another; let the fore-finger lie in the direction of the lines of force as found by a compass (FORe and FORce), and let the thumb point in the direction of motion of the conductor at the moment, (thuMb and Motion), then the direction which the middle finger takes is that of the induced current (Induced and mIddle). When the direction of the current is found, remember that *in the armature* the current flows from the negative brush to the positive. The rule is applied in a similar manner to find the direction of rotation of a motor armature, but the left hand must be used in place of the right.

This is a particularly useful rule in an electrical drawing-office, and I made a little folding pocket apparatus on the same principle of which I give an illustration. It has three arms: When not in use the one representing motion will fold down flat on to that representing

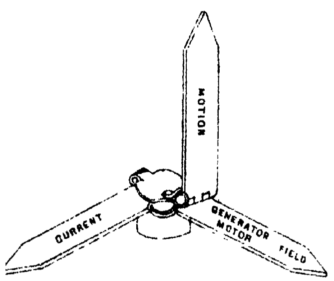


Fig. 70.

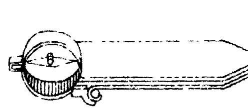


Fig. 71

lines of force, while that representing current slides in between the other two; in use the current arm will open out either to left or right, for motor or generator.

Calculation of shunts.—I will now give you the formulæ employed in calculating a shunt winding for a dynamo, and a fully worked out example. The shunt coils in question were required to give about 5,000 ampère-turns per arm with potential difference of 60 volts. The magnet bars in this case were $5\frac{1}{2}'' \times 4\frac{1}{2}''$ in cross section and the 'formers' or spools are always just large enough to slip easily on to the bars. The total depth of flange available for wire was $1\frac{1}{8}''$ and the width between flanges 8". These two quantities are known as *dw.* (depth of winding) and *lw.* (length of winding). As a rule the total available *dw.* is not utilised, and in the present instant 1·1" was the actual *dw.* taken up. There were two formers only, and they were to be coupled in series.

Now the first thing to be done is to find out what will be the average length of one turn of wire when the former is wound, for of course the

inside coils are shorter than the outer ones, and we require the mean of the whole lot or *ml.* (mean length). The actual periphery inside the former will be twice the periphery of the bar, *plus* an extra amount

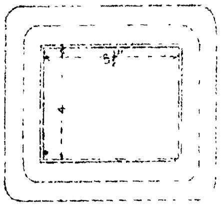


Fig. 72.

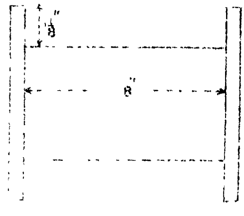


Fig. 73.

for the air space and insulation of the 'former.' The latter factor may be taken as almost constant, say 2 inches generally. Therefore *ml.* of lowest layer$=2(5\frac{1}{2}+4)+2$ inches or 21 inches; with any given depth of winding we must add π *dw.* to this to find the mean length.*

Our *ml.* will then be—

$2(5\frac{1}{2}+4)+2+3{\cdot}14\times1{\cdot}1=19+2+3{\cdot}45=24''{\cdot}45$, or ·68 yard.

The area of the wire required is now found as follows:—

$$\text{Area} = \frac{{\cdot}000028 \times ml.\text{ in yards} \times \text{ampère-turns per arm required}}{\text{E. M. F. over one former}},$$

·0000277 is, you will remember, the resistance of 1 yard of pure copper 1 square inch in section at the working temperature of a dynamo; we have just found the *ml.*; the required ampère turns are 5,000 per arm and the E. M. F. over one former is half the total, or 30 volts. Working out the above calculation we find that $\frac{{\cdot}000028 \times {\cdot}68 \times 5000}{30} = {\cdot}00318$ square inches is the required area of the wire. Now if we wound up to the right depth with No. 16 S.W.G., the area of which is ·00322 square inch, the result would be near enough practically; but in the present case the only wires available at the moment were ·060 diam. and ·070 diam., the one too large and the other too small, and a suitable combination of these two had to be found to give the right ampère-turns—

·060	area ·00283,	turns per inch	12·4
·070	„ ·00384,	„ „	11·5

The turns per inch were obtained from the figure for thickness of double cotton covering (p. 104), this being the usual insulation for magnet wires. From these we can find out at once how many layers of wire can be put into 1·1 inches of *dw.*, and how many turns there will be of each sized wire in an *lw.* of 8·5 inches. Whichever size of wire is used about 13 layers can be wound on, since average turns per inch × *dw.* = layers, *i.e.*, $12\times1{\cdot}1=13$. Now the ·″060 diam. wire is the nearest to the size we require, so there must evidently be more of that than of the other. It is a matter of trial and error to find the proportion

* You will see how this is arrived at by a consideration of the figure (on this page) where the dotted line represents the middle layer of wire, the four corner arcs—drawn in full lines—representing the excess of length over the bare periphery of the former. These four arcs together make up a circle of the radius of half *dw.*, and π times the full *dw.* gives the length of the four arcs.

of layers, but in this instance the best result is given with 8 layers of ·″060 and 5 layers of ·″070, giving depth of winding of ·″65 and ·″43 respectively.

The turns per layer 8·5 in. length will be—

for ·″060 ... 12·4 × 8·5 = 104
for ·″070 ... 11·5 × 8·5 = 95

and the total turns will be—

for ·″060 . 8 layers 832 turns } total 1,307 turns.
for ·″070 ... 5 „ 475 „ }

We must now find the mean length for each size of wire, assuming the ·″060 to be wound on first—

ml. of ·″060 = 19 + 2 + ·65 × 3·14 = 23″·03 = ·64 yards
„ „ ·″070 = 23″·03 + ·43 × 3·14 = 26·41 = ·705 „

The resistance of the shunt (Rs) is—

$$\frac{\cdot 000028 \times m.l. \text{ in yards} \times \text{total turns}}{\text{area of wire in square inches}}$$

or for the ·″060 = $\frac{\cdot 000028 \times \cdot 64 \times 832}{\cdot 00283}$ = 5·28 ohms hot, and for the ·″070 = $\frac{\cdot 000028 \times 705 \times 475}{\cdot 00384}$ = 2·45 ohms hot.

Rs for the two formers in series = 2(5·28 + 2·45) = 15·46 ohms hot.

(Instead of the above constant ·000028 we can use ·0000245 to find the cold resistance, which works out to 13·7 ohms for the 2 formers.)

Shunt current (Cs) = $\frac{\text{total E. M. F.}}{\text{total hot resistance}} = \frac{60}{15 \cdot 46}$ = 3·89 ampères.

The total effective exciting power of the shunt is then 2 × Cs × total turns per arm = 2 × 3·89 × 1,307 = 10,200 ampère-turns, or 5,100 ampère-turns per arm, which is sufficiently near to the requirements.

There are one or two other points to be cleared up before leaving this subject. Thus having two wires of different size we must see that the smallest can convey the whole shunt current without damage. Current Density = $\frac{\text{current}}{\text{area}} = \frac{3 \cdot 89}{\cdot 00283}$ = 1,370 ampères per square inch in the ·″060-wire. This is quite a reasonable allowance in a shunt winding.

Next let us see what weight of wire is required.

Weight = area × *ml. in inches* × number of turns × ·32 × number of formers (·32 is a constant, the weight of a cubic inch of pure copper being ·3212 lbs.)

Weight of ·″060 = (·00283 × 23·03 × 832 × ·32) 2 = 35lbs.
„ „ ·″070 = (·00384 × 26·41 × 475 × ·32) 2 = 30 „

Total ... 65 „

This 65lbs. represents pure copper; the double cotton covering adds some 8 per cent. to the weight in this size of wire, so the actual total will be about 70lbs.

Lastly, we must see that there is sufficient radiating surface to dissipate the heat generated in the shunt. The outside surface of the wire will be the periphery × *lw.*

Periphery = 19 + 2 + (3·14 × 1·1) 2 = 27·″9.
Therefore surface = 27·9 × 8·5 = 237 square inches.

The total watts lost in heat in each former are found by $W = C^2R$.
$C^2R = 3{\cdot}89^2 \times 7{\cdot}73$ (total resistance of one former hot) $= 15{\cdot}17 \times 7{\cdot}73 = 117$ watts.

Therefore the watts per square inch surface are $\frac{117}{237} = {\cdot}49$, which, though rather high, is not excessive. With the same amount of wire wound on a longer *lr.* and with a smaller *dw.* the figure would be reduced, since the surface would be increased and the watts kept practically constant.

Calculation of starting resistances.—I have previously given you an example of a "shunt resistance" for bringing down the volts of a machine. I will now give one of a "starting resistance" of a motor. If a motor is suddenly switched fully on, there is practically a short circuit for a moment, since the full E.M.F. is thrown across the low resistance of the stationary armature. As soon as the speed begins to rise the armature generates an E.M.F. opposed to that of the circuit, which prevents the high initial current from being maintained. The starting resistance fulfils the function of the back E.M.F. until the latter has had time to come into existence, and it is necessary for two reasons, namely, first to prevent damage to the motor, and, secondly, to prevent a sudden flicker in the lights on the circuit, owing to the momentary drop in pressure on the mains. This is accomplished by having a resistance in the external circuit at the time of switching on and reducing it gradually as the speed rises, until it is done away with. The diagram shews the arrangement in the case of a compound motor.

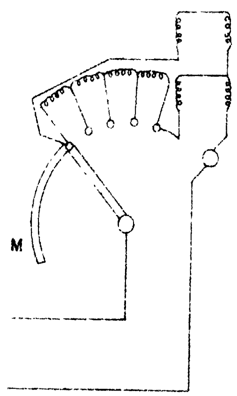


Fig. 74.

With the switch in the position shewn on contact 1, the shunt circuit is closed and the machine is therefore excited; when the movable arm M. is put on contact 2 the armature and main coil circuit is closed through the three coils of resistance, which are calculated so that not more than about double the normal current can get through in the first rush. Contacts 3 and 4 each cut out one coil, and contact 5 puts the motor direct on the mains. The long tongue on M. continues all the time to make connection with contact 1 and thus supply the shunt. Now the motor in this case gave 2 B. H. P., the input being

220 volts and 10 ampères. Allowing 20 ampères at starting the total resistance must be $\frac{220}{20} = 11$ ohms. Of this the armature was 1·4 ohms and the main winding ·3 ohm, so the starting resistance had to be altogether 9·3 ohms, divided into three equal sections of 3·1 ohms each. As the 20 ampères is only momentary it will be sufficient if the platinoid carries, say, 14 ampères, and with these figures the size and length of wire can be worked out as in the case of the shunt resistance. I may here call your attention to the fact that the shunt in this diagram is known as a "long shunt," to distinguish it from the "short shunt," which is coupled across the brushes only and does not take in the main.

Central station curves.—I have some "curves"* to shew you, taken while I was at the central station of the Hove Electric Light Company; they illustrate excellently some of the usual conditions of central station supply, though the different conditions of latitude, temperature, and climate generally, would modify them in this country. The curves are some six years old, and as the Company was then fairly young it has long ago outstripped the modest totals of those days, though the shape of the curves probably remains sensibly the same.

First, we have a set shewing weekly, for two whole years from the original start, the units generated in the station and those recorded on the consumers' meters, together with the cost in pence per unit, the total lamps connected, and the lbs. of coal used per unit (Plate 3). It needs no explanation for you to see that as the output of the station increases the price per unit diminishes, since the cost of management, labour, interest on capital and other standing charges remain practically constant, while even the variable items, coal, &c., are used more economically when there is a large output. The vertical distance between the two output curves in any case represents to scale the units "lost, stolen or strayed," chiefly lost in the mains. Similar curves here in Calcutta may not shew such a very great difference between cold- and hot-weather outputs, since the difference in the hour of sunset is not nearly so marked, but this will perhaps be balanced by the great influx of visitors and cold-weather residents.

The next curve (Fig. 75) is a typical one of the daily load in the English winter, showing the total ampères (at 110 volts) hourly, and the total terminal volts (3-wire system) during the heavy load hours. You will notice the current curve rises soon after 6-30, when people begin getting up, keeping at a steady maximum from 7-30 to 8 A.M., when the sun rises, and then dropping rapidly. Soon after 3 P.M. there is again a rapid rise, culminating at about 6 P.M., when both houses and shops are on together. This particular case happens to be for the day before Christmas, but ordinarily the peak comes at the dinner hour on week days and about the end of church time on Sundays. After this the current drops rapidly as the shops close, there being only a temporary revival at about 9 P.M., when the houses are at a maximum, since both dining-room, drawing-room and bed-room lights are often on simultaneously. This curve shews how very low the 'load factor' is, and illustrates the

* The figures are not actually curves, but point-to-point diagrams, since the drawing of a 'mean curve' would spoil the characteristic features in some cases.


AMPÈRES AT 110 VOLTS
TERMINAL VOLTS
250
240
230
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
a.m
p.m
a.m
TIME

Fig. 75.

function of the battery (referred to in Lecture V) of cutting off the peak of the curve. The second curve gives the rise of the E.M.F. at the dynamo terminals, and of course closely corresponds with the current line. The noticeable thing about this curve is the lowness of the "day load," though in the hot weather this is more remarkable still. In this respect Calcutta will prove very different from England, since the extensive use of rotary fans will ensure a steady day-load throughout about nine months in the year.

Engines and dynamos have to be provided of sufficient power to take nearly the maximum load (except that the battery cuts off a little at the peak of the curve), and the most economical working would be obtained if they were working always at full load. The ratio between their actual daily output and their maximum output is called the "load factor," and upon the largeness of this factor the economical working of the station depends. Hence the great value, from the point of view of the supplier, of a day-load, such as the supply of power to motors for rotary fans, &c.

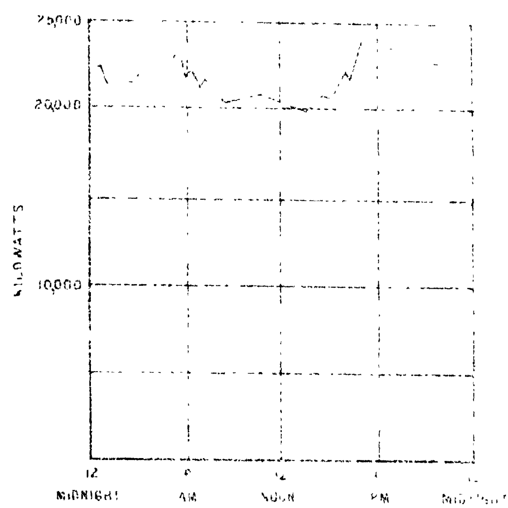


Fig. 78

Evidently it is the works which supply power for industrial purposes, not merely lighting, which have the best chance of a good load factor, and as an illustration of this I am able to show you a most interesting load curve taken from a recent number of "The Electrician." It indicates the total load, on December 10th, 1899, at the works of the Niagara Falls Power Company and shows a load curve which must be the envy of every other similar undertaking in the world. It will be seen that throughout the whole 24 hours there is a nearly constant load of from 20,000 to 24,000 kilowatts, and this uniformity of load has been a feature of the concern since it started some eight years ago. When I was

there in the winter of 1894 there were two generating sets working, while a third was in course of erection; now there are ten sets erected, and preparations are being made to commence a new station for ten more, each consisting of a two-phase alternating current dynamo coupled direct to a 5,000 horse-power turbine. Of all this immense power the largest consumers are the Union Carbide Company, who have just laid down works, close to the power house, for the manufacture of Carbide of Calcium—used, as you know, in the production of the latest rival illuminant to electricity, acetylene; these works utilize some 15,000 E. H. P. constantly. Other uses of the power are for manufacturing aluminium, carborundum, &c., in works close by, while a large amount is transmitted a distance of 25 miles to Buffalo. A somewhat similar scheme, sensationally talked about in the Press as "harnessing the Cauvery," is, I believe, taking shape in India at the present time.

The last two figures, with which I conclude my lectures, shew the units generated every day of the week both at Christmas time and in an ordinary week. In both cases you will notice that Sunday gives

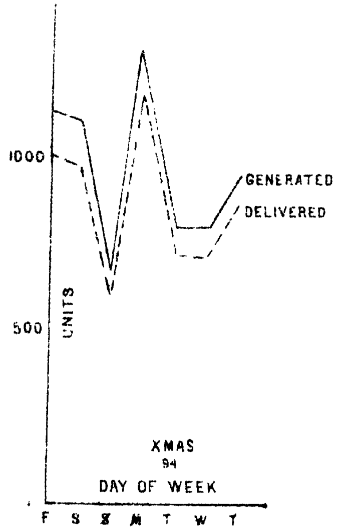


Fig. 77.

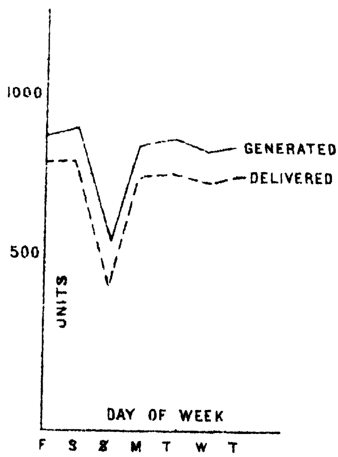


Fig. 78.

much the lowest result, but Christmas Day and the holiday following it are also very low, as the shops are not open, while the day before Christmas gives the highest aggregate figure of the year as a rule.

I have now come to the end of my remarks, and trust that you have gathered some hints which will prove useful to you in your subsequent work. I think I have erred on the right side in being too elementary rather than otherwise, for it is attention to small and simple details that makes for success just as disregard of them inevitably spells failure.